NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

BENCHMARKING THE NAVAL SYSTEMS ENGINEERING GUIDE AGAINST THE INDUSTRY STANDARDS FOR SYSTEMS ENGINEERING

by

Brian A. Borchardt

September 2012

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2012	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE Benchmarking the Naval Systems Engineering Guide against Industry Standards			**5. FUNDING NUMBERS**
6. AUTHOR(S) Brian Borchardt			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ___N/A____.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release, distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

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14. SUBJECT TERMS Systems Engineering Policy			**15. NUMBER OF PAGES** 99
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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Approved for public release, distribution is unlimited

BENCHMARKING THE NAVAL SYSTEMS ENGINEERING GUIDE AGAINST THE INDUSTRY STANDARDS FOR SYSTEMS ENGINEERING

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 2012

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ABSTRACT

The *Naval Systems Engineering Guide* (NESG) was written in 2004 by representatives from NAVSEA, NAVFAC, NAVAIR, NAVSUP and MARCORSYSCOM. Since then, three other foundational systems engineering documents have been written or revised: the *International Standards Organization* (ISO) *Standard 15288* in 2008, the *International Council on Systems Engineering* (INCOSE) *Systems Engineering Handbook in 2011*, and The guide *to the Systems Engineering Body of Knowledge* (SEBoK) in 2012. This thesis compares the treatment of one life cycle element, in-service engineering, across all four documents, in order to offer a comparative analysis of the *NESG* in light of key industry standards and make recommendations for the revision of the *NESG*. The gap analysis performed in relation to crucial industry documents suggests that future revisions of the *NSEG* should include substantial discussion of Operations, Maintenance, Service Life Extension and Disposal Processes, as well as identify best practices for each process.

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LIST OF ACRONYMS AND ABBREVIATIONS

CUUM:	Capabilities Update, Upgrades and Modernization
DoD:	Department of Defense
DoN:	Department of the Navy
DSMC:	Defense Systems Management College
ECSS:	European Cooperation on Space Standardization
EIA:	Electronic Industries Alliance
INCOSE:	International Council on Systems Engineering
ISO:	International Standards Organization
MARCORSYSCOM:	Marine Corps Systems Command
MOU:	Memorandum of Understanding
NASA:	National Aeronautics and Space Administration
NAVAIR:	Naval Air Systems Command
NAVFAC:	Naval Facilities Command
NAVSEA:	Naval Sea Systems Command
NAVSUP:	Naval Supply Command
NSEG:	Naval Systems Engineering Guide
RPG:	Rocket Propelled Grenade
SE:	Systems Engineering
SEBoK:	Systems Engineering Book of Knowledge
SEMG:	System Engineering Management Guide
SLE:	Service Life Extension
SLEP:	Service Life Extension Program

SPAWAR:	Space and Naval Warfare Systems Command
USA:	United States Army
USAF:	United States Air Force
USMC:	United States Marine Corps
USN:	United States Navy

EXECUTIVE SUMMARY

This thesis compares the *Naval Systems Engineering Guide* (NSEG) to the *International Standards Organization* (ISO) *Standard 15288*, *International Council on Systems Engineering* (INCOSE) *Systems Engineering* (SE) *Handbook* and the *Systems Engineering Body of Knowledge* (SEBOK). By examining and determining current standards of practice in these key documents, focusing on the in-service engineering area of Operations, Maintenance, Service Life Extension and Upgrades, and Disposal, this analysis identifies areas where updates or revisions to the *NSEG* can meet or exceed industry standards of practice.

Naval engineers and their contractors need to have up to date standards to ensure that they are getting the best equipment possible for the war fighters at the best price available; hence, the necessity to determine where the NSEG needs to be revised and updated. In addition, due to the long service life of most military equipment, there can be significant gains in terms of process, costs and efficiency by utilizing SE techniques even years after the systems have been put into service. This thesis examined what in-service techniques and methods are commonly present in industry standards and should be included in a future revision of the *NSEG*.

The *NSEG* does not presently address in-service engineering techniques. The *NSEG* mentions in-service engineering areas in a discussion of the systems lifecycle, showing timelines and graphics showing where they should happen. This means that any additional focused attention on other dimensions of in-service engineering knowledge needs to be drawn from industry standards and then modified (as necessary) for Naval purposes. The industry standards that were reviewed in this thesis research cover all of the desired areas in the level of detail necessary for effective SE: they could easily be adapted to the needs of the Navy. It is recommended that an *NSEG* revision incorporate content related to in-service engineering from the *ISO 15288*, *INCOSE's Guide to Systems Engineering*, and the *SEBoK*.

The *ISO 15288* has bare-bones information on Operations, Maintenance and Disposal of a system, but does not cover Service Life Extension and Upgrades. The use of this guide as a primary model would be good for the *NSEG* if a minimal amount of direction is desired to be given to contractors and Naval engineers.

The INCOSE SE Handbook has more detail than the *ISO 15288* on Operations, Maintenance and Disposal of a system, but also does not cover Service Life Extension and Upgrades. *The INCOSE SE Handbook* also includes informative summary diagrams that are both useful and effective tools that should be included in future revisions of the NSEG. The use of this guide for as a primary model would be best if the desired model for the future NSEG was to be more informative and offer explicit directions.

The SEBoK contains extensive detail on Operations, Maintenance, Service Life Extension and Upgrades and Disposal. *The SEBoK* by far has the most extensive and lengthiest coverage of the four reviewed standards both for the particular areas of interest and for the subject of SE as a whole. The use of this standard would be best for the Navy, if the desire is for *NSEG* to give extensive direction and detail on these areas.

After reviewing all of the standards, this thesis determined that a combination of all three industry standards provides the best information for a revision to the *NSEG*. The best attributes for each of the areas of interest are summarized below:

With respect to operations:

- Adopt an overall Model similar to the one present in INCOSE's guide, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- The five elements from this diagram and program would be effective if populated from all three manuals.

- Adopt the Data Gathering Suggestions from the *SEBoK* guide, to provide the necessary data for studying various operations and functions so that improvements based off this data analysis can be made for future blocks and/or iterations of the system.
- Adopt the emphasis on Customer Support and Feedback from *ISO 15288*, as having good communication is vital to maintaining a healthy relationship between all involved parties.

With respect to maintenance:

- Adopt an overall Model similar to the *INCOSE Guide*, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- The five elements from this diagram and program would be effective if populated from all three manuals.
- Adopt the emphasis on historical records from the *ISO 15288* and the *INCOSE Handbook*, as maintaining diligent records will aid in making changes and updates to maintenance procedures, tools and personnel qualifications.
- Adopt the emphasis on training that is included in all three manuals.
- Adopt the emphasis on consistency to establish a pattern for various Maintenance activities, as this will allow new methods and Operational changes to be made if necessary (i.e., more downtime than originally planned or retraining of Operational techniques because they are putting undue wear and tear on certain components).

With respect to service life extensions:

- Adopt an overall Model similar to the *INCOSE* one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- Adopt an emphasis on cost, as in order to modernize or upgrade a system, it must be more cost effective than a replacement product for the system would be, both short term and long term.
- Adopt an emphasis on obsolescence. Are the spare parts, tools and qualified personnel on hand to keep the products running? If not, then upgrades or modernizations may be required to keep the system running.

With respect to system upgrades:

- Adopt an overall model similar to the *INCOSE* one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- Adopt an emphasis on cost, as in order to extend a system, it must be more cost effective than a replacement product in both the short and long term.
- Adopt an emphasis on obsolescence, to keep the spare parts, tools and qualified personnel on hand to keep the products running.

With respect to disposal:

- Adopt an overall Model similar to the INCOSE one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- The five elements from this diagram and program would be effective if populated from all three manuals.
- Adopt the emphasis on environmental concerns for disposal and recycling that are present in all three manuals.
- Adopt an emphasis on record keeping to preserve data for historical reference and as proof that products were properly disposed of IAW all applicable laws, standards and regulations.
- Adopt an emphasis on making Disposal plans part of the process from the very beginning, and plan that they will be modified to address changes in the product itself and changing laws and regulations that govern it over the course of its lifetime.

By including in-service engineering in the NSEG and by continually updating its processes and procedures every few years, the Navy can ensure that the NSEG is giving its work force the best tools from a systems engineering perspective. This does not guarantee that the best services or systems will make it into the hands of war fighters, but it will help to ensure that the best techniques are being used. These techniques will ensure that the Navy is getting the proper “bang for its buck” and that systems operate more smoothly and efficiently than those that do not utilize proper techniques.

ACKNOWLEDGMENTS

- Mary Vizzini, who has put much effort into helping me catch up to my thesis timeline and answered all of my inane formatting questions.
- Dr. Olwell, who helped me develop a topic and finish graduate school on time, despite an extremely condensed schedule.
- Mike Frey, who has allowed me to miss much work to finish school despite taking over after I was already in this program.
- And finally Cody and Hollie Borchardt and the rest of my friends and family, who have supported me in all of my lame-brained ideas including graduate school with a full time job and family.

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I. INTRODUCTION

A INTRODUCTION TO SYSTEMS ENGINEERING

1. Problem Definition

Systems Engineering (SE) is a multi-disciplinary study that encompasses many fields, ranging from specialized engineering fields (i.e., mechanical, electrical, et cetera) to logistics to program management; and it is a field that is becoming more crucial as an area of academic and practical study as components and systems become more complex and more items are integrated into larger networks. For the purposes of this discussion, the definition of SE that will be used comes from the *INCOSE Systems Engineering Handbook* :

> Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (Haskins, 2011)

The increased complexity of military hardware, both new systems and their integration with legacy systems, requires a correspondingly increased expertise in Systems Engineering. Because Systems Engineering covers a wide range of topics and areas and these topics all require extensive integration and integration oversight, only by utilizing the most current and accepted methods and tools can Systems Engineers expect to maintain military hardware in the most efficient and cost effective way possible. This thesis seeks to examine how SE affects military hardware from a technical standards and methods point of view, specifically related to in-service engineering areas in the field. This is a major concern for military hardware that often has a long operational life and/or has its operational life extended and upgraded extensively during its lifecycle.

This thesis examines the *Naval Systems Engineering Guide* and how it compares against three primary industry standards. These standards are the *International Standards Organizations* (ISO) *15288*, the *International Council on Systems Engineering* (INCOSE) *Systems Engineering Handbook* and the *Systems Engineering Body of Knowledge* (SEBoK). The comparison will focus primarily on in-service engineering, including Operations, Maintenance, System Upgrades and Service Life Extension, and System Disposal. The *NSEG* does not cover in-service engineering techniques, making industry standards the primary source material for where to derive content for future revisions to the *NSEG*.

2. Military Integration

Military systems have become increasingly complex and capable. This complexity has even reached to the individual U.S. Army soldier or Marine level. Where once an infantryman would be equipped with only weapons and body armor, he now also carries sophisticated sensor, communications, and computing equipment, and may control additional ground and airborne unmanned vehicles. Looking at historical data, soldiers have moved from approximately 55 lbs. of gear to over 100 lbs. of gear for "marching," and the weight for "assault" operations is an additional 60 lbs of weight, with more gear being added as more sophisticated sensing equipment becomes available Little of that added weight involves weapons or armor that actually is becoming lighter as new technologies and composites are utilized (Task Force Devil, 2003). The primary weight increase involves the electronic gear that is being added to standard kit.

Note for a moment that it takes several Human Systems Integration Engineers, multiple electronic and computer Engineers, material engineers and mechanical engineers to envision and build the items listed above. In order to make all these pieces and parts work together, a System Engineer should be involved at the various stages of integration, testing and during the lifecycle of the equipment. It also conceivable that gear and weapons that are more advanced are being designed for future war fighter use and that these items will have to be introduced and integrated as they come online to the soldier "system." These upgrades will be a continual improvement process as war fighters are given better tools to do their jobs and to protect themselves from enemy combatants. This will require continual process improvement that a Systems Engineer will be able to facilitate smoothly.

If we shift from the single person who is a "grunt" to something more complicated and sophisticated, i.e., a warship, submarine or even a jet fighter, suddenly these technological advances and integration requirements multiply exponentially. Multiple systems engineers are now needed for each of these entities, and then an even larger number of systems engineers are required to get all of these systems to work together into the "systems of systems" concept. The ships, submarines, and aircraft work together to form a battle group and each vehicle will be utilizing a variety of technologies at various stages of modernization that may have to work together in ways in which they were not originally intended. This overall integration project is not a fantasy, it is a daily fight that Fleet commanders have to wage as their assets are upgraded and changed at different rates. It is imperative Systems Engineers make this integration process as simple as possible to aid in Fleet operations and engagements.

All of these issues tie into the next set of questions that emerges as the levels of complexity involved in interoperating or systems-of-systems are considered: What governs all of these systems and Systems Engineers to ensure they are using both best practices and the same practices? Are Naval Systems Engineers using the proper standards, techniques and methods when they are working? Examining these questions forms the basis for the research conducted for this thesis.

3. Need for Unified Standards

The DoD does not built or create systems anymore in terms of hardware, software or in some cases, concepts, either as components or projects; this has now become the purview of defense contractors, both large and small. Instead, the government generates a requirement or need and then goes out to industry and asks: Who can meet that need? Answers to this question will come from companies of varying size, competency and experience and in some cases, there will even be multiple companies building the same item or different components of the same item that are all deemed to fit the bill. In order to ensure that the multiple companies are building items that meet DoD requirements, it is imperative to make certain that they are all using the same standard or comparable ones.

While one would think that there is coherency among those contractors and others building and creating to meet DoD needs, with builders and creators all working to the same sets of standards and rules for their production, this is often not the case. The situation might occur where one company wants to utilize ISO standards and one company wants to utilize INCOSE standards on two similar projects, and these two projects are supposed to integrate together. Will they be able to do that and produce an item to the same performance standards? These questions raise an interesting dilemma because SEBoK standards were based off of INCOSE standards that were based off of ISO standards, making all of these standards related. How close are the “child” standards to the “parent”?

In order for the United States Navy to have a unified Systems Engineering Plan, it needs to have an up to date and flexible guide for contractors and for Naval Systems Engineers. The *NSEG* has not been updated since 2004, while three major industry standards have been modernized over the last 8 years. In January of 2008, ISO published ISO/IEC 15288:2008, which was a replacement for ISO 12207 (their SE standard for the previous 10 years) that was intended to update all changes made in the SE field, provide backwards compatibility and move users towards “harmonized standards” (Roedler & Jones, 2008). In 2011, INCOSE published version 3.2.2 of their Systems Engineering Handbook that incorporated changes made in the ISO 15288 and is a document targeted specifically at engineers both in and out of the field of SE (Haskins, 2011). In 2012, SEBoK published their *Systems Engineering Body of Knowledge V.75*, which is intended to be a guide to all items SE related, with the ability to point people in the correct direction about particular topics related to different areas of SE (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012). Each of these standards have been through several revisions, with more changes likely in the future as SE is a continually evolving and changing field.

A constant, fluid revision process is necessary for a document to remain relevant in the systems engineering world because of the rapid pace of computer and technological advances that society is beginning to experience. If the USN wants to remain on the cutting edge of technology for both weapons and peacetime equipment, it must give its contractors the tools (guides and instructions) and flexibility to do business with all options on the table. Using updated standards and techniques is one set of tools that are invaluable during their creation, modernization, operation and disposal processes.

4. Previous Work in this Area

Few documents address topics similar to the line of study that is being followed in this document. In 1998 two systems engineers performed a similar study of the current military and civilian SE standards and it helped inform Systems Engineers what current models should be used at the time (Sheard & Lake, 1998). This study not only looked at what was currently in use for SE but also which instructions were currently under revision and/or being created for the first time. The SMC SE Primer & Handbook is an Air Force document that addresses the “basics” of SE for juniors Systems Engineers, Project Officers and engineers from other disciplines (Space & Missile Systems Center, 2005). This guide is primarily geared toward Space Systems and their associated support equipment and processes but the relevant parts to this thesis are the summaries of “undeniable facts of SE” and the referral to the INCOSE SE Handbook as a primary source of “more-in depth” information (Space & Missile Systems Center, 2005).

B. HISTORY OF THE NAVAL SYSTEMS ENGINEERING GUIDE

1. MIL-STD 499 and DSMC

Military Standard 499 was the original DoD SE guide that was written in 1969 by the USAF and was 32 pages long (USAF Systems Command, 1969). It was developed from the USAF AFSCM 375-1 that had been published two years earlier and was itself a gathering of knowledge from previous experience and work in acquisition and design (Bashaw & Gardella, 1967). The USAF Systems Command was responsible for MIL STD-499 and the entire DoD was responsible for using it (USAF Systems Command, 1969). That engineering authors wrote a standard only 32 pages in length indicates a great transformation has occurred between 1969 and the present time in terms of the complexity of systems: MIL-STD 499A, written in 1974 also suggests a less complicated field: that version only had 24 pages (USAF Systems Command, 1974). These standards only contained the broadest definitions of common Systems Engineering and Program management terms and sent the readers to other standards, guides and technical manuals to get more specific requirements, methods and techniques (USAF Systems Command, 1969).

In 1983, the Defense Systems Management College (DSMC) developed their original Systems Engineering Management Guide (SEMG) with a follow on update in 1990 (Kockler, Withers, Poodiack, & Gierman, 1990). This guide was derived from MIL STD 499A and industry textbooks, and was aimed specifically as an introduction to SE from a Program Managers perspective (Kockler, Withers, Poodiack, & Gierman, 1990). This guide is over 300 pages long, contained significantly more information than MIL-STD 499 series, was focused exclusively on defense acquisition programs and was developed exclusively by military and DoD defense personnel (Kockler, Withers, Poodiack, & Gierman, 1990).

The writing of the DSMC SEMG led to the DoD beginning work on MIL STD 499 Revision B (JOINT OSD Working Group, 1993). It was 70 pages long and contained significantly more detail than the previous versions of the MIL STD series. This version discussed SE sections and terms in more detail and specificity than previous versions, gave specific direction for processes and even gave guidance for conducting reviews and creating schedules (JOINT OSD Working Group, 1993). This version was never completed or officially published and was ultimately replaced by the EIA/IS 632 standard, which was a combined effort between government and industry partners (JOINT OSD Working Group, 1993).

2. EIA/IS 632

In June 1994, a working group of industry associations, the International Council on Systems Engineering (INCOSE), and the Department of Defense developed an interim standard for the engineering of systems; and this effort was led by the G-47 Committee on Systems Engineering of the Electronic Industries Alliance (EIA) (Department of Navy, 2004). From this working group, a standard was written and that standard was the *EIA/IS 632* (Department of Navy, 2004) (Phillips, 2012). The *EIA/IS 632* was intended to provide a standard for use by commercial enterprises, as well as government agencies and their development contractors and was the replacement for *MIL-STD 499B* which was still in its draft format (Department of Navy, 2004).

3. NSEG

The *Naval Systems Engineering Guide* was published in October 2004 as a joint effort by the primary engineering commands of the United States Navy (USN) (Department of Navy, 2004). The *NSEG* was fashioned from the Electronic Industries Alliance (EIA) EIA/IS 632 and updating it with inputs from NAVSEA, NAVAIR, NAVSUP, MARCORSYSCOM and SPAWAR in order to create a document that all could satisfactorily use and implement. The *NSEG* was created in direct response to the directive from the Undersecretary for Defense for Acquisition, Technology and Logistics (Wynn, 2004) and was implemented by Joint Memorandum of Understanding (MOU) according to the following conditions:

> By reference (a), the Acting Under Secretary of Defense (Acquisition, Technology and Logistics) signed into policy the requirement that 'All programs responding to a capabilities or requirements document shall apply a robust Systems Engineering (SE) approach that balances total system performance and total ownership costs within the family-of-systems, system-of-systems context. Accordingly, a SE Plan shall be developed for Milestone Decision Authority approval in conjunction with each Milestone review.' SE must be embedded in program planning and performed across the entire acquisition life cycle. SE provides the integrating technical processes to define and balance system performance, cost, schedule, and risks. (Massenburg, Langerich, Stone, Rodriguez, & Catto, 2004)

This tasking from the USECDEF AT&L underscores that the entire DoD was beginning to take SE seriously. The quick turnaround by the USN (less than six months) is an amazingly quick action for a big bureaucracy like the upper echelons of the military, which helps enforce the idea that all levels of senior government were taking this idea of having to update U.S. Systems Engineering practices seriously. The only possibly distressing part of this whole series of events is that the *NSEG* has not been updated since 2004, and eight years is a long time when thought of in terms of technology upgrades and changes. This is only possibly distressing because that guide may or may not be current and that uncertainty is something that will be determined through the course of this discussion.

C. INDUSTRY STANDARDS FOR SYSTEMS ENGINEERING

1. INCOSE

The International Council on System Engineering (INCOSE) is a large group of academic and professional engineers whose mission is "to share, promote and advance the best of systems engineering from across the globe for the benefit of humanity and the planet" (Haskins, 2011). With over 8000 members from over 50 countries and over 20 years since its inception, it is fair to say that INCOSE has a good sampling of all sorts of various experiences, training and work that enable their knowledge base to be both well-formed and well-respected. The board members from INCOSE include both federal and DoD entities, in addition to the many civilian companies which gives their knowledge base a wide spread. In addition, INCOSE members actually were part of the original *EIA/IS 632* working group that was the precursor to the *NSEG* (INCOSE Administration, 2011).

INCOSE published their first version of a Systems Engineering Guide in 1994 and the organization has gone through multiple edits, corrections and iterations since that time in order to keep its standards up to date. The current version is 3.2.2, published in October of 2011, and is nearly 400 pages long (Haskins, 2011). The fact that there have been eight revisions to the original manual over a 17-year period lends some credit to the fact that SE is a continually changing field as people gain a greater understanding and appreciation for the discipline. This constant revising process also shows the importance of having a dedicated Systems Engineer (not merely a mechanical or electrical engineer filling in) working for a company or division whose primary job is keeping on top of all the knowledge and changes to the field to ensure compliance and use of new tools and methods.

2. ISO

The International Standards Organization (ISO) is a universally recognized group that publishes standards for a wide range of disciplines, ranging from Engineering to Business to Health and Human Services. They advertise themselves as publishing a set of “voluntary standards” and have created over 19,000 of them since being founded in 1947. This group is based out of Switzerland and can count members from over 164 countries and from over 3300 technical groups that aid in their development and manufacturing. While compliance with their standards is considered voluntary, most companies take it as both a mark of pride and are more likely to be considered as viable business partners if they possess the appropriate ISO certification (ISO, 2012).

The version of the *ISO 15288* systems engineering standard that will be examined for this study was published in January of 2008 and is only 81 pages in length (Roedler & Jones, 2008). The primary reason for the relatively short length of this ISO instruction (and most other ISO instructions) is that ISO focuses more on emphasizing the importance of having processes and being consistent with those processes, as opposed to actually telling an organization how to implement processes (ISO, 2012). According to ISO, the following benefits have been gained from utilizing their standards:

- Cost savings - International Standards help optimize operations and therefore improve the bottom line
- Enhanced customer satisfaction - International Standards help improve quality, enhance customer satisfaction and increase sales
- Access to new markets - International Standards help prevent trade barriers and open up global markets
- Increased market share - International Standards help increase productivity and competitive advantage
- Environmental benefits - International Standards help reduce negative impacts on the environment
- *Benefits in figures:*
- *GBP 2.5 billion* - annual contribution standards make to the UK economy
- 80% - percentage of world trade impacted by International Standards
- *AUD 100 million* - benefits to Australian economy from sampling standards in the mining industry
- *84%* reduction in transportation time due to standardization of container transport (ISO, 2012)

These statistics apply to the entire line of ISO standards, not just the SE specific ones, but the implication is that all of their standards are winning propositions for the organizations that uses them and the organizations with whom they do business.

3. Systems Engineering Body of Knowledge

The System Engineering Body of Knowledge (SEBoK) is a relatively recent industry standard that was first published in 2010. The SEBoK is a collaborative effort led by Stevens Institute of Technology and the Naval Postgraduate School that gathers “all systems engineering knowledge” into one exhaustive, extensive place in order to ensure that knowledge is available for SE professionals.

> The SEBoK is intended to be a guide to the body of knowledge, but does not seek to capture all the knowledge directly. It provides references to more detailed sources of knowledge, and is constructed to facilitate easy update as the field evolves and new sources of knowledge emerge. The SEBoK is also intended to be global in applicability. Despite the challenge that SE is practiced differently from industry to industry and country to country, the SEBoK must be useful to systems engineers around the world. The authors have been chosen from a diverse set of locales and industries to help ensure its broad applicability.” (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012)

The purpose that the SEBoK publishers define for themselves in creating this standard is summarized in Table 1.

Task Name	Task Description
Inform Practice	Inform systems engineers (glossary) about the boundaries, terminology, and structure of their discipline and point them to useful information needed to practice SE in any application domain (glossary).
Inform Research	Inform researchers about the limitations and gaps in current SE knowledge that should help guide their research agenda.
Inform Interactors	Inform performers in interacting disciplines (system implementation, project and enterprise (glossary) management, other disciplines) of the nature and value (glossary) of SE.
Inform Curriculum Developers	Inform organizations defining the content that should be common in undergraduate and graduate programs in SE.
Inform Certifiers	Inform organizations certifying individuals as qualified to practice systems engineering.
Inform SE Staffers	Inform organizations and managers deciding which competencies (glossary) that practicing systems engineers should possess in various roles ranging from apprentice to expert.

Table 1. Purpose of SEBoK, table from (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012)

The current version of the SEBoK is V0.75. It was published in March of 2012, is 678 pages long, and is the second revision in 1.5 years. The editors plan to release a final Version 1.0 in September 2012 (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012). The SEBoK draws heavily from the INCOSE SE handbook and many other industry sources so when it is complete, it should be a one stop shopping guide that greatly reduces the reference and standard searching that academics, students and industry workers perform in their daily SE activities. This guide will ultimately be able to give the proper guidance or point someone in the proper direction to gain the needed guidance for their research and/or work related to the SE field.

II. METHODOLOGY

A. AREAS OF COMPARISON

1. In-service Engineering

As previously stated, the main focus of this discussion will be on Systems Engineering for items that are already in-service. One of the first questions that comes to mind after reading this purpose would be "Why do we care about SE for items that are already in-service?" The answer to this question is twofold: the first is that it is never too late to start applying Systems Engineering, even if it is to systems already in use, because there are always improvements that can and in some cases should be made to systems. Some of the older technologies that are still in-service more than likely never had a robust, or in fact, any kind of SE plans during their initial construction. Adding SE processes and methods even late in the system lifecycle can add significant value to a system from a functionality, integration and disposal standpoint.

The second answer to this question is more complicated and it is that many "obsolete" technologies are now being extended beyond their original service life and/or being using in ways for which they were not originally designed or intended. Ships and airframes that were once only intended to last 30 years now have to last 35 or 40, due to funding shortfalls or mission changes. This means computer and weapon systems need to be upgraded and integrated into new battle group and joint warfare units. Technologies and weapon systems that were designed for hunting submarines or aircraft are now being used to hunt down drug runners and pirates.

For example, the USS Nicholas aided in the interdiction of a vessel carrying nearly 5,000 pounds of cocaine just two months ago off the coast of Columbia (Phillips, 2012) and a month before that, the USS Elrod interdicted nearly 1,000 pounds in the Caribbean (U.S. Naval Forces Southern Command and U.S. 4th Fleet Public Affairs , 2012). While this capability is obviously in their repertoire, chasing down small boats and seizing contraband does not exactly fit in the original mission profile for an anti-submarine warfare frigate with a limited air warfare capability. Since the Cold War ended and hunting submarines is not as important as it once was, the US Navy management and engineering personnel found an additional use for frigates that still have significant hull life left (Federation of American Scientists, 2011). Adaption and modification are significant parts of SE thinking and methodology that need to be well used and available to war fighters with ever changing missions.

B. DATA GATHERING PLAN

1. NSEG Research

The first portion of this chapter involved fact-finding in the NSEG particularly in the areas that are associated with in-service engineering applications. These areas included Operations, Maintenance, Service Life Extension, System Upgrades and finally Disposal. Since this manual is the standard that is desired to be updated/changed, it was important to establish a baseline on where the NSEG stands. Once it was understood where the NSEG stood on in-service SE practices, then it was easier to know what to search for in the industry standards. This section also discussed the importance of particular areas in the in-service lifecycle to aid in the fact finding for the other standards.

2. Industry Standards Research

The next portion of this chapter is an examination of the *ISO 15288*, *INCOSE SE Handbook* and *SEBoK*, to determine what was in each manual concerning in-service equipment, processes and methods. This information was necessary for comparison to the *NSEG* in the gap analysis process. A gap analysis is useful for answering the questions posed in this thesis, as can be seen from the following definition of it. A gap analysis is

> “A technique for determining the steps to be taken in moving from a current state to a desired future-state. Also called need-gap analysis, needs analysis, and needs assessment. Gap analysis consists of (1) listing of characteristic factors (such as attributes, competencies, performance levels) of the present situation ("what

is"), (2) cross listing factors required to achieve the future objectives ("what should be"), and then (3) highlighting the gaps that exist and need to be filled." (The Business Dictionary, 2012)

C. DATA ANALYSIS PLAN

1. Standard Comparison

Once the in-service SE data was gathered from the four primary sources under consideration, each of the three industry standards was compared to the NSEG and to each other in order to understand what (if any) are the differences that need to be updated and/or considered in the NSEG. Once the comparison to the NSEG was completed, the industry standards were compared to one another to understand the differences and different takes by each one concerning in-service areas. These three industry standards are derivatives of one another, so there were no major differences or changes made in each successive standard, just some omissions or emphasis changes on one area or another. These differences were fully analyzed and explained in conclusions and recommendations sections.

D. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

After all of the data was gathered and analyzed, conclusions were drawn and discussed. These conclusions were relatively straightforward because either the standards had the same data requirements and methods as the *NSEG* and each other or they did not. All discrepancies that were discovered were addressed and what they actually meant to the revision process was discussed here. This section discusses each of the four in-service areas in depth and draws conclusions about each one as they relate to all four standards.

2. Recommendations

This section consists of two parts. The first set of recommendations is for changes that should be made for the next iteration of the *NSEG*. This was determined from the gap analysis that was performed between the *NSEG* and the three major industry standards. The second set of recommendations are what courses of inquiry are suggested for further study. The existing gap analysis for the in-service sections of these standards makes it safe to assume that it will be necessary to explore the other sections of the *NSEG* and the other three standards to determine the differences in all sections of the manuals.

III. INDUSTRY STANDARDS DATA GATHERING

A. DEFINITION OF TERMS

1. System Operations

Systems Operations is the phase in the life cycle that begins after Verification and Validation and continues until System Disposal (Department of Navy, 2004). This phase covers all level of Operation from the normal operating procedures and conditions to the extreme and/or emergency portions of the system. Depending on the product, this phase could be considerably longer than any other phase of the products life cycle, so it is important to have a robust SE plan for this phase (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

A likely starting point for Operations is a plan for sustained operations and this includes coordinating staff and schedules, creating acceptance criteria for changes and modifications and coordinating the replacement of legacy systems (Roedler & Jones, 2008). Other service considerations can be a range of activities, from fuel to transportation to contractor support, and the exact needs for these criteria will be determined on a by-project basis (Haskins, 2011). Part of this plan will be utilizing trained, qualified personnel and this can be difficult because for many new systems, the "right" people may be difficult to identify initially and pin down, making this a fluid portion of a project (Haskins, 2011). Flexibility will be necessary here, as in all steps of this phase, further strengthening the need for SE practices.

2. System Maintenance

System Maintenance covers all repair work scheduled and unscheduled that needs to be done a system on both a normal and emergency basis (Roedler & Jones, 2008). Everything from changing a screw on a set basis to replacing a damaged circuit board (an emergency) falls under this "phase" and it should be just as long as the Systems Operations Phase (i.e. occurring throughout the active lifecycle of the system). This section of the SE guide should include how to account for planned and unplanned maintenance from a logistical, personnel and material standpoint (Haskins, 2011). This phase can easily be one of the more difficult ones to predict because it is conceivable that for new construction there will only be estimates of what will need to be repaired or replaced until a large enough sampling of maintenance records can be analyzed (Haskins, 2011). Part of this phase will likely include re-examination and rewriting of the technical manuals to correct deficiencies or over planned maintenance (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

The first major part of Maintenance is the people involved in the process. Having the correct personnel is imperative because just having untrained personnel will not get you very far (Haskins, 2011). Personnel need to have the necessary maintenance and trouble-shooting skills for the particular equipment they are working on and for the tools that they need to use for the maintenance they are expected to perform (Haskins, 2011). These personnel will have to work within the constraints that they are given (time limits, part limits, etc.) and have the competence to provide feedback into the system incase changes or recommendations need to be made (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

The constraints the need for maintenance places on a system are often part of the initial acceptance/ design parameters (i.e., system will only be down 10% of the time for scheduled maintenance and 5% of the time for unscheduled maintenance). Downtime is not operational time, so having the proper constraints and personnel can help keep a system operating as designed. It is important that systems are designed for maintainability, because maintenance is less likely to be performed if it is too difficult or challenging (Haskins, 2011). By gathering data about how maintenance is actually performed, who performs it and how long it takes (as opposed to how the system was intended to be maintained), changes to maintenance procedures, tools and personnel can be made throughout a system's lifecycle (Haskins, 2011). In addition to following constraints, proper procedures will need to be followed to ensure a system is taken care of as the manufacturer intends.

Maintenance procedures are created for a reason, usually because the manufacturer determined that it was the best way to keep a system up and operating correctly. In order to keep the system in the best shape it should be maintained when and how the manufacturer suggests as best as the operators can manage. If there is an obvious flaw or defect found in the maintenance procedures, tools or required personnel this should be provided back to the manufacturer and program management people so that the proper corrective actions can be taken (Haskins, 2011).

3. System Upgrades

This phase of Operations really covers two areas: Service Life Extension and System/Capability Upgrades (Pyster & Olwell, Product and Service Life Management, 2012). Service Life Extension is just as the title sounds; using the system for longer than it was planned and built to be in use. The reasons for this can be because a replacement system is not yet ready, a system was more robust than originally planned, or the system is being re-purposed for another task (Pyster & Olwell, Product and Service Life Management, 2012). Regardless what reasoning is used, there will need to be an examination of both the technical and fiscal aspects of the system to ensure that due diligence was used in extending a system's life (Pyster & Olwell, Product and Service Life Management, 2012).

System Upgrades can include both planned and unplanned changes to the original system. A good example of this is a Naval Ship, specifically an aircraft carrier that has a hull life of 50+ years and can expect upgrades on most weapon, radar and sonar systems especially at the planned nuclear refueling period which starts at approximately they 24th year of service life (Federation of American Scientists, 2011). Some of these replacements will be planned for systems that are in the design or test phase when the ship is completed, and other upgrades will come as a result of a new capability or need that is defined for the system (Greenert, 2012). The new need may come from a mission change for the system or because a new threat in need of being countered has been discovered (Greenert, 2012).

4. System Disposal

This final phase is important for several reason, the most important probably being that the planet has a finite number of resources. Systems need to be properly disposed of, both to protect the environment and to maximize the potential for recycling (Pyster & Olwell, Product and Service Life Management, 2012). A system might have hazardous materials (nuclear, chemical or biological) that require special considerations to make them safe for disposal and this is a consideration that should be built into the entire lifecycle plan, not just thought of when a system is being prepped for retirement (Haskins, 2011). The recycling portion is a consideration both from a limited resource perspective and from a fiscal perspective, and in the currently tight fiscal environment, income from recycling is useful. Using a Ship Disposal Project started in 1999, the Navy has dropped the price from recycling ships from $1100 per ton to just pennies per ton in just over ten years (Team Ships, 2012).

Having a plan is important in the Disposal process to ensure that a disposal has been adequately performed to take care of all possible concerns (Roedler & Jones, 2008). Primary concerns would be dangerous or toxic material that needs to be disposed of or made safe according to certain procedures, or items that contain a government classification or company propriety information (Haskins, 2011). There may even be personnel files or data in old computer systems that previous users left on the systems and these items need to be “wiped” for protection purposes (Pyster & Olwell, Product and Service Life Management, 2012). A proper disposal plan will cover all of these concerns and more.

A Disposal Phase needs to follow a comprehensive plan in order to ensure that nothing is missed. Following the steps of the actual plan is a good way to ensure that the concerns discussed in the previous sections are addressed (Haskins, 2011). Following a systematic process will ensure things are accomplished in the order designated to be best for system disposal and to be sure nothing is missed. These systematic instructions will likely have been planned out many years prior to system disposal so it is conceivable that changes may have to be made to the plan along the way for large numbers of the same system that have to be disposed of (Pyster & Olwell, Product and Service Life Management, 2012).

Finalizing the disposal is important because having proof of what processes and procedures were followed is important for all legal and environmental issues that arise from Disposal (Pyster & Olwell, Product and Service Life Management, 2012). In addition to these legal concerns, it is good to have a history, so the disposal knowledge is available for future projects of a similar nature that will at some time need to be disposed of (Haskins, 2011). Even if future projects are not similar, if good processes are practiced and can be adapted for future disposal, then these historical records have value.

B. NSEG

1. Summary

The NSEG does not specifically address the Systems Operations Phase or in fact any in-service topics that are being handled in this report. The NSEG covers all phases from the initiation of an idea to the creation, testing and deployment of an item but ends with Verification and Validation. The only mention of any of the in-service topics is on a few different diagrams that shows where they are on the life cycle of a product (Department of Navy, 2004). The coverage of the NSEG for in-service engineering is not adequate on any of the topics previously listed.

C. ISO 15288

1. System Operations

ISO 15288 will be the first industry standard that is examined because it is the “parent” standard for INCOSE and is the simplest of the three. ISO 15288 breaks the systems operations phase of the SE down into five phases: Prepare for Operations, Perform Operational Activation and Checkout, Use the System for Operations, Perform Operational Problem Resolution, and Support the Customer (Roedler & Jones, 2008). Each of these major activities has several sub-steps that aid in the explanation of SE duties for each particular phase.

Under the Prepare for Operations, there are three basic sub steps:

- Prepare a strategy for operation,
- Obtain other services related to operation of the system
- Assign trained qualified personnel to be operators (Roedler & Jones, 2008).

Performing Operational Activation and Checkout only has one sub-step and that is “activate the system in its intended operational situation to deliver instances of service or continuous service according to its intended purpose” (Roedler & Jones, 2008). This step tells the operators to operate their systems and ensure that all functions perform as they are supposed to and is the “last” step prior to the system going into full use and operation. Ideally, any last minute corrections or bugs will be discovered at this point to aid in future construction and/or prevent any in-service catastrophes.

Use System for Operations has three sub-steps:

- Consume materials, as required, to sustain the services;
- Monitor operation to ensure that the system is operated in accordance with the operations plans, in a safe manner and compliant with legislated guidelines concerning occupational safety and environmental protection; and
- Monitor the system operation to confirm that service performance is within acceptable parameters (Roedler & Jones, 2008).

Perform Operational Problem Resolution has 3 sub-steps:

- Perform failure identification actions when a non-compliance has occurred in the delivered services;
- Determine the appropriate course of action when corrective action is required to remedy failings due to changed need;
- Introduce remedial changes to operating procedures, the operational environment, human-machine interfaces and operator training as appropriate when human error contributed to failure (Roedler & Jones, 2008).

This section consists of standard troubleshooting steps of finding out what went wrong and how to fix it. This can be a human, hardware or procedural mistake and it will be the job of the Systems Engineer to figure out exactly what went wrong.

Finally, Support the Customer has one sub-step: Continuously or routinely communicate with users to determine the degree to which delivered services satisfy their needs (Roedler & Jones, 2008). Communication is the key to success in all situations and SE processes are extremely important especially from a feedback standpoint. The SE company wants to establish a good relationship both for the possibility of repeat or recommended business and from a good product standpoint. Most engineers take pride in their work and want to help their customers out and if a customer does not communicate that there is a problem, then it will be hard for the engineers to be as helpful as they can be.

2. System Maintenance

ISO 15288 defines the purpose of System Maintenance as "The purpose of the Maintenance Process is to sustain the capability of the system to provide a service. This process monitors the system's capability to deliver services, records problems for analysis, takes corrective, adaptive, perfective and preventive actions and confirms restored capability." (Roedler & Jones, 2008). The desired outcomes of the system maintenance process are:

- A maintenance strategy is developed
- Maintenance constraints are provided as inputs to requirements
- Replacement system elements are made available

- Services meeting stakeholder requirements are sustained
- The need for corrective design changes is reported and Failure and lifetime data is recorded (Roedler & Jones, 2008).

The guide than further breaks this area down to Maintenance Planning and Performance that each have several associated sub-steps.

Planning the Maintenance has two sub-steps: Prepare a maintenance strategy and Define the constraints on system requirements that are unavoidable consequences of the maintenance strategy (Roedler & Jones, 2008). Prepare a Maintenance strategy is further broken down into four sub-steps:

- The corrective and preventive maintenance strategy to sustain-service in the operational environment in order to achieve customer satisfaction;
- The scheduled preventive maintenance actions that reduce the likelihood of system failure without undue loss of services, e.g. suspension or restriction of the services
- The number and type of replacement system elements to be stored, their storage locations and conditions, their anticipated replacement rate, their storage life and renewal frequency
- The skill and personnel levels required to effect repairs and replacements, accounting for maintenance staff requirements and any relevant legislation regarding health and safety, security and the environment. These procedures include disassembly strategy, fault diagnosis techniques, re-assembly and testing sequences. (Roedler & Jones, 2008)

Performing Maintenance is broken down into eight sub-steps:

- Obtain the enabling systems, system elements and services to be used during maintenance of the system.
- Implement problem reporting and incident recording to guide diagnosis of individual events and histories to support future corrective, adaptive, perfective and preventive maintenance.
- Implement the procedures for correction of random faults and/or scheduled replacement of system elements.
- Initiate corrective action to remedy previously undetected design errors.
- Confirm that logistics actions satisfy the required replenishment levels so that stored system elements meet repair rates and planned schedules.

- Perform preventive maintenance by replacing or servicing system elements prior to failure, according to planned schedules and maintenance procedures.
- Perform failure identification actions when a non-compliance has occurred in the system.
- Maintain a history of problem reports, corrective actions and trends to inform operations and maintenance personnel, and other projects that are creating or utilizing similar system entities. (Roedler & Jones, 2008)

3. System Upgrades

ISO 15288 does not have a specific section on system upgrades and/or service life extension. There are a few feedback "loops" integrated into the operations and maintenance procedures for product and process improvement but that is all that is currently addressed on this subject. This is an area of study and work has looked into extensively at this point by ISO and this could be because the phenomena of extensive system life extension and upgrade are primarily the concern of the military.

4. System Disposal

ISO 15288 defines the purpose of Disposal Process is to end the existence of a system entity (Roedler & Jones, 2008). The desired outcomes of the Disposal process are:

- A system disposal strategy is defined.
- Disposal constraints are provided as inputs to requirements.
- The system elements or waste products are destroyed, stored, reclaimed or recycled.
- The environment is returned to its original or an agreed state.
- Records allowing knowledge retention of disposal actions and the analysis of long-term hazards are available.

The disposal process is then further broken down into three different sub-steps: Plan the Disposal, Perform the Disposal and Finalize the Disposal.

Planning the disposal has three sub-steps:

- Define a disposal strategy for the system, to include each system element and any resulting waste products.
- Unavoidable constraints on the system design arising from the disposal strategy are communicated.
- Specify containment facilities, storage locations, inspection criteria and storage periods if the system is to be stored. (Roedler & Jones, 2008)

Performing the disposal has six sub-steps:

- Acquire the enabling systems or services to be used during disposal of a system.
- Deactivate the system to prepare it for removal from operation.
- Withdraw operating staff from the system and record relevant operating knowledge.
- Disassemble the system into manageable elements to facilitate its removal for reuse, recycling, reconditioning, overhaul, archiving or destruction.
- Remove the system from the operational environment for reuse, recycling, reconditioning, overhaul or destruction.
- Conduct destruction of the system, as necessary, to reduce the amount of waste treatment or to make the waste easier to handle (Roedler & Jones, 2008).

Finalize the Disposal has two sub-steps:

- Confirm that no detrimental health, safety, security and environmental factors exist following disposal.
- Archive information gathered through the lifetime of the system to permit audits and reviews in the event of long-term hazards to health, safety, security and the environment, and to permit future system creators and users to build a knowledge base from past experiences (Roedler & Jones, 2008).

5. Summary

The ISO 15288 has adequate coverage on the Operations, Maintenance and Disposal phases of in-service engineering. Most of the minimum information that is needed to perform these functions is presented though there is a lack of extensive detail. The major critique of each section is a lack of standard recognition or identification. The ISO 15288 does not address Service Life Extension or Upgrades at all so any such information would have to be obtained from another standard.

D. INCOSE SE GUIDE

1. System Operations

The INCOSE SE Handbook begins its operations section with the definition from ISO 15288 as a starting point and then adds some further description and a figure to help reinforce the concepts it will be presenting. Figure 1 below is a reproduction from the INCOSE SE Handbook.

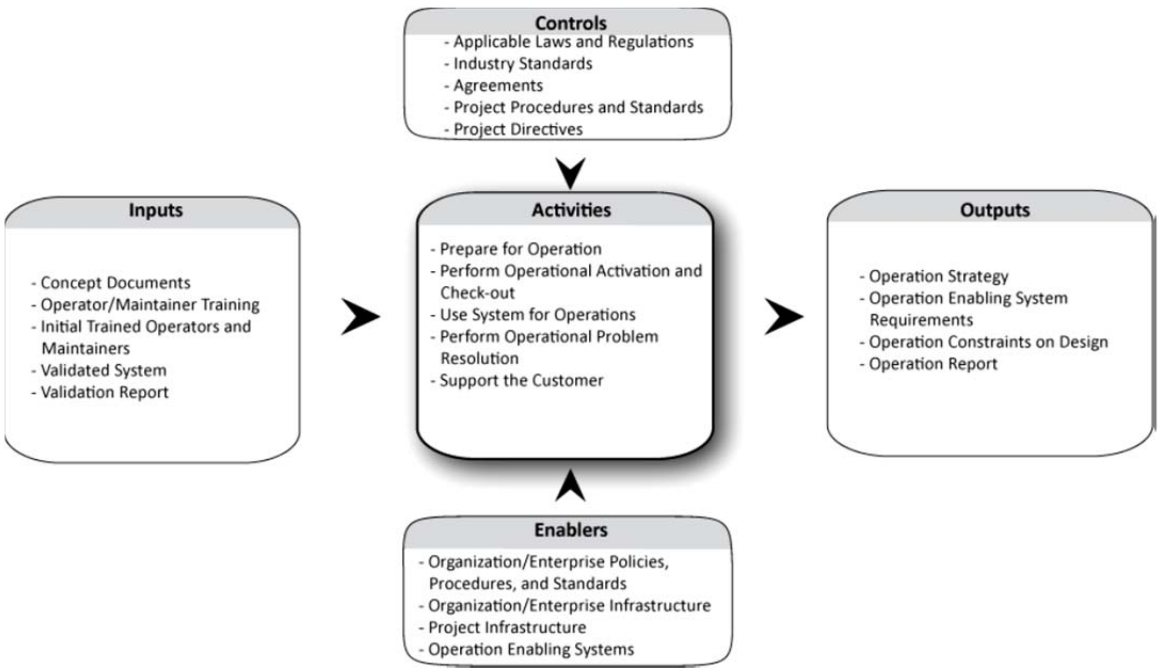

Figure 1. Diagram from INCOSE SE Handbook, Operations Diagram (Haskins, 2011)

As this figure shows, INCOSE breaks down Operations into a series of Activities that produce Outputs. Feeding into these Actions there are Inputs, Controls and Enablers that shape the Outputs. The expanded lists and some explanation when required are listed below.

The Inputs according to INCOSE are:

- *Concept Documents* – Concept documents generated early in the life cycle are used to direct the activities of this process
- *Operator/Maintainer Training*
- *Initial Trained Operators and Maintainers* – Operation of the system includes the humans that will operate, maintain, and sustain the system
- *Validated System*
- *Validation Report* – Including documentation of the validation activity results, a record of any recommended corrective actions, Design Feedback/Corrective Actions taken, and evidence that the system element or system satisfies the requirements, or not (Haskins, 2011).

The enablers and controls are grouped together and they are:

- Applicable Laws and Regulations
- Industry Standards – relevant industry specifications and standards
- Agreements – terms and conditions of the agreements
- Project Procedures and Standards – including project plans
- Project Directives
- Organization/Enterprise Policies, Procedures, and Standards – including guidelines and reporting mechanisms
- Organization/Enterprise Infrastructure
- Project Infrastructure
- Operation Enabling Systems (Haskins, 2011).

The desired Outputs for INCOSE are:

- *Operation Strategy* – Including staffing and sustainment of enabling systems and materials
- *Operation Enabling System Requirements* – Requirements for any systems needed to enable operation of the system-of-interest need to be developed
- *Operation Constraints on Design* – Any constraints on the design arising from the operation strategy to influence future design and specification of similar systems or reused systems-elements
- *Operation Report* – Including:

- System performance reports (e.g., statistics, usage data, and operational cost data)
- System trouble/anomaly reports – with recommendations for appropriate action (Haskins, 2011).

Finally the Activities according to INCOSE are:

- Prepare for Operation
- Perform Operational Activation and Check-out
  - Provide operator training and maintain qualified staff
- Use System for Operations
  - Execute ConOps for the system-of-interest
  - Track system performance and account for operational availability
  - Perform operational analysis
- Perform Operational Problem Resolution
  - Manage operational support logistics
  - Document system status and actions taken
  - Report malfunctions and make recommendations for improvement
- Support the Customer (Haskins, 2011).

In addition to the format listed above the INCOSE guide also includes "common approaches and tips" in each section. In the Operations process, there is one tip and it is:

> Depending on the nature of agreements between different organizations, the development team may continuously or routinely communicate with users to determine the degree to which delivered services continue to satisfy their needs. The system may exhibit unacceptable performance when system elements implemented in hardware have exceeded their useful life or changes in the operational environment affect system performance. In the event of system failures or anomalies, it may be necessary to conduct engineering investigations to identify the source(s) of the failure and determine appropriate corrective actions. Systems engineers can assist in these activities. (Haskins, 2011)

2. System Maintenance

The INCOSE SE Handbook also begins its Maintenance section with the ISO 15288 definition for Maintenance. The standard also has a diagram along similar lines to the Operations process with Inputs, Controls and Enablers feeding into Actions to produce Outputs that are shown in Figure 2.

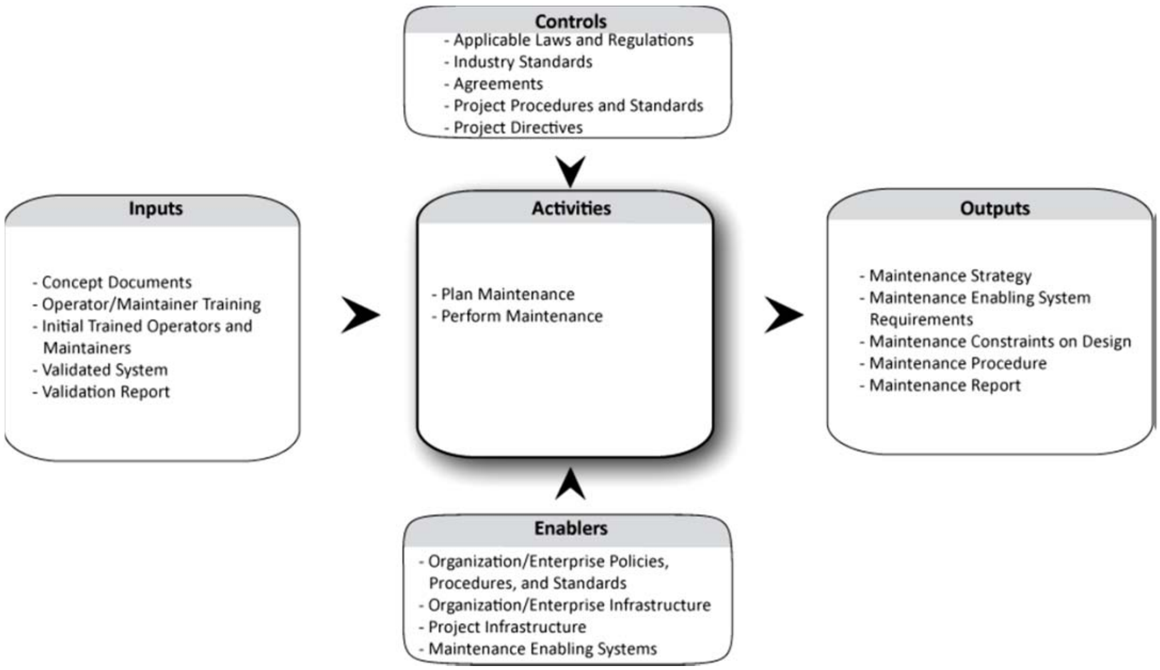

Figure 2. Diagram from INCOSE SE Handbook, Maintenance Process (Haskins, 2011)

The desired Inputs for the Maintenance Process are:

- *Concept Documents* – Concept documents generated early in the life cycle are used to direct the activities of this process
- *Operator/Maintainer Training*
- *Initial Trained Operators and Maintainers* – Operation of the system includes the humans that will operate, maintain, and sustain the system
- *Validated System*
- *Validation Report* – Including documentation of the validation activity results, a record of any recommended corrective actions, Design Feedback/Corrective Actions taken, and evidence that the system element or system satisfies the requirements, or not (Haskins, 2011)

The Controls and Enablers for the Maintenance Process are:

- Applicable Laws and Regulations
- Industry Standards – relevant industry specifications and standards
- Agreements – terms and conditions of the agreements
- Project Procedures and Standards – including project plans
- Project Directives
- Organization/Enterprise Policies, Procedures, and Standards – including guidelines and reporting mechanisms
- Organization/Enterprise Infrastructure
- Project Infrastructure
- Maintenance Enabling Systems (Haskins, 2011)
- The desired Outputs from the Maintenance Process are:
- Maintenance Strategy – Accounts for the system's technical availability, replacements for system elements and logistical support, maintenance personnel training and staff requirements
- Maintenance Enabling System Requirements – Requirements for any systems needed to enable maintenance of the system-of-interest need to be developed
- Maintenance Constraints on Design – Any constraints on the design
- arising from the maintenance strategy
- Maintenance Procedure
- Maintenance Report – Including documentation of the maintenance activity results, reporting of failures and recommendations for action, and failure and lifetime performance data. This report also documents any required procedure or system changes that should be accomplished as part of on-going configuration management activities (Haskins, 2011)

There are two main Activities for the Maintenance process and they are:

- Plan Maintenance
    - Establish a maintenance strategy
    - Define maintenance constraints on the system requirements

    - Obtain the enabling systems, system elements, and other services used for maintenance of the system
    - Monitor replenishment levels of spare parts
    - Manage the skills and availability of trained maintenance personnel
- Perform Maintenance
    - Implement maintenance and problem resolution procedures –including scheduled replacement of system elements prior to failure (i.e., preventive maintenance)
    - Maintain a history of failures, actions taken, and other trends to inform operations and maintenance personnel and other projects creating or utilizing similar system elements
    - Monitor customer satisfaction with system and maintenance support (Haskins, 2011)

The common approaches and tips for Maintenance are:

- Use historic data and performance statistics to maintain high levels of reliability and availability and to provide input to improve the design of operational and future systems.
- Planning for maintenance begins early in the system life cycle with the development of supportability criteria. These criteria, which include reliability and maintainability requirements as well as personnel, training, facilities, etc., are included in the defined stakeholder requirements or system specification to ensure that they are considered in the system design.
- Maintain configuration management control throughout the Utilization and Support Stages in support of the Maintenance Process. (Haskins, 2011)

3. System Upgrades

The INCOSE SE Handbook also does not have a section dedicated to System service life extension and upgrading, but there are a few parts of the standard that address some aspects of the process. When describing the "support stage" of the system lifecycle INCOSE states:

> Modifications may be proposed to resolve supportability problems, to reduce operational costs, or to extend the life of a system. These changes require SE assessment to avoid loss of system capabilities while under operation. The corresponding technical process is the Maintenance Process. (Haskins, 2011)

INCOSE SE Handbook also makes provides a framework to determine if a products lifecycle should be extended based on costs and obsolescence of the product.

4. System Disposal

This standard also begins its Disposal section with the disposal definition from the ISO standard. The familiar INCOSE style diagram is used with Inputs, Controls and Enablers feeding into Activities to produce Outputs and that diagram is reproduced in Figure 3.

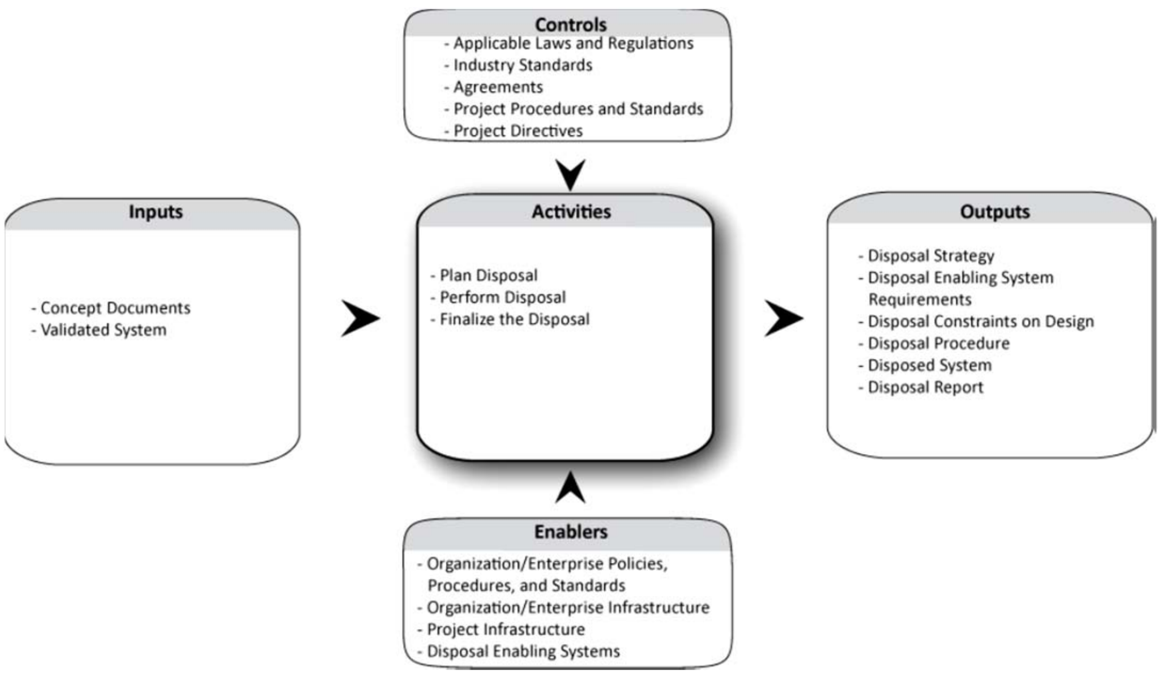

Figure 3. Diagram from INCOSE SE Handbook, Disposal Process (Haskins, 2011)

The Inputs to the Disposal Process are:

- *Concept Documents* – Concept documents generated early in the life cycle are used to direct the activities of this process.

- *Validated System* – The Disposal Process works on a depleted system of system elements (e.g., batteries) meaning that if production and operational environments must be restored to former conditions, details of the initial state are relevant. (Haskins, 2011)

The Controls and Enablers for the Disposal process are:

- *Applicable Laws and Regulations*
- *Industry Standards* – relevant industry specifications and standards
- *Agreements* – terms and conditions of the agreements
- *Project Procedures and Standards* – including project plans
- *Project Directives*
- *Organization/Enterprise Policies, Procedures, and Standards* – including guidelines and reporting mechanisms
- *Organization/Enterprise Infrastructure*
- *Project Infrastructure*
- *Disposal Enabling Systems* (Haskins, 2011)

The desired Outputs for the Disposal process are:

- *Disposal Strategy*
- *Disposal Enabling System Requirements* – Requirements for any systems needed to enable disposal of the system-of-interest need to be developed
- *Disposal Constraints on Design* – Any constraints on the design arising from the disposal strategy
- *Disposal Procedure*
- *Disposed System*
- *Disposal Report* – Including documentation of the disposal activity results, may include an inventory of system elements for reuse/storage and any documentation or reporting required by regulation or organization standards (Haskins, 2011)

The Actions that are part of the Disposal Process are:

- Plan Disposal
    - Review the Concept of Disposal, including any hazardous materials and other environmental impacts to be encountered during disposal

    - Define the Disposal Strategy
    - Impose associated constraints on the system requirements
- Perform Disposal
    - Deactivate the elements to be terminated
    - Disassemble the elements for ease of handling
    - Remove the elements and any associated waste products from the operational site – includes removing materials from storage sites and consigning the elements and waste products for destruction or permanent storage
- Finalize the Disposal
    - Maintain documentation of all Disposal activities and residual hazards (Haskins, 2011)

The common approaches and tips for the Disposal section are:

- The project team conducts analyses to develop solutions for ultimate disposition of the system, constituent elements, and waste products based on evaluation of alternative disposal methods available. Methods addressed should include storing, dismantling, reusing, recycling, reprocessing, and destroying end products, enabling systems, system elements, and materials.
- Disposal analyses include consideration of costs, disposal sites, environmental impacts, health and safety issues, responsible agencies, handling and shipping, supporting items, and applicable federal, state, local, and host-nation regulations.
- Disposal analyses support selection of system elements and materials that will be used in the system design, and should be readdressed to consider design and project impacts from changing laws and regulations throughout the project life cycle.
- Disposal Strategy and design considerations are updated throughout the system life cycle in response to changes in applicable laws, regulations, and policy.
- Consider donating an obsolete system. – Many items, both systems and information, of cultural and historical value have been lost to posterity because museums and conservatories were not considered as an option during the disposal stage.
- Concepts such as Zero Footprint and Zero Emissions drive current trends toward corporate social responsibility that influence decision making regarding cleaner production and

operational environments and eventual disposal of depleted materials and systems.

- The ISO 14000 series includes standards for Environmental Management Systems and Life-Cycle Assessment.
- Instead of designing cradle-to-grave products, dumped in landfills at the end of their 'life,' a new concept is transforming industry by creating products for cradle-to-cradle cycles, whose materials are perpetually circulated in closed loops. Maintaining materials in closed loops maximizes material value without damaging ecosystems (Haskins, 2011).

5. Summary

The *INCOSE SE Handbook* has good-to-adequate coverage of all areas of Operations, Maintenance and Disposal areas of in-service engineering. There is great emphasis placed on standards for every section and at least some mention of the other areas deemed important. The *INCOSE SE Handbook* is unique in that it uses diagrams to summarize its main points and this is viewed as a positive experience because pictures help to get points across in ways that paragraphs sometimes cannot. There is no coverage of Service Life Extension or Upgrades so each that information will have to be obtained from another standard. The INCOSE SE Handbook demonstrates what needs to be the case as far as systems engineering processes go. However, it does not say how to do it, which is something that the *NSEG* will need to do.

E. SEBOK

1. System Operations

The SEBoK follows some of the similar methodologies for their processes that are in the INCOSE SE Handbook for the Systems Operations section. It begins with the definition of Operations from the ISO 15288 and then adds some additional discussion on the subject. The SEBoK then moves into a process approach section and states that data collection and analysis are the main functions for SE during this phase (Pyster, Olwell, & et-al, System Deployment and Use, 2012). The recommended data to be gathered is:

- Updating training and development of new training as required for operational and support personnel. Training is generally developed early with system design and production and executed during integration and operations. Determination of training updates or changes will be based on evaluation of the operational and support personnel.
- Evaluation of operational effectiveness. Early in the planning phases of a new system or capability, measures of operational effectiveness are established based on mission and business goals. These measures are important during system operation. These attributes are unique for each system and represent characteristics describing the usefulness of the system as defined and agreed to by system stakeholders. Systems engineers monitor and analyze these measurements and recommend actions.
- Failure reporting and corrective actions (FRACA) activities will involve the collection and analysis of data during operations. FRACA data will provide trends involving failures that may require design or component changes. Some failures may also result in safety issues requiring operational modifications until the offending elements under analysis can be corrected. If components or systems must be returned to maintenance facilities for corrective repairs, there will be operational and business impacts due to increased unavailability and unplanned transportation cost (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

The SEBoK then lists applicable Methods and Tools:

- Operations manuals will provide operators the steps and activities required to run the system.
- Training and Certification. Adequate training must be provided for the operators who are required to operate the system. The objectives of training are to:
    - Provide initial training for all operators in order to equip them with the skill and knowledge to operate the system. Ideally, this process will begin prior to system transition and will facilitate delivery of the system. It is important to define the certification standards and required training materials up front (for more information on material supply, please see Logistics).
    - Provide continuation training to ensure currency of knowledge.

- Monitor the qualification/certification of the operators to ensure that all personnel operating the system meet the minimum skill requirements and that their currency remains valid.
- Monitor and evaluate the job performance to determine the adequacy of the training program (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

According to the SEBoK the result of the implementation of a successful Operations process will:

- an operation strategy is defined and refined along the way;
- services that meet stakeholder requirements are delivered;
- approved, corrective action requests are satisfactorily completed; and
- stakeholder satisfaction is maintained (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

The SEBoK then lists the Outputs of the Operations Process:

- operational strategy, including staffing and sustainment of enabling systems and materials (this may incorporate the strategy first defined during the transition process);
- system performance reports (statistics, usage data, and operational cost data);
- system trouble/anomaly reports with recommendations for appropriate action; and
- operational availability constraints to influence future design and specification of similar systems or reused system elements (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

Finally, the Operations section ends with the Activities of the process:

- provide operator training to sustain a pool of operators;
- track system performance and account for operational availability;
- perform operational analysis;
- manage operational support logistics;
- document system status and actions taken; and
- report malfunctions and recommendations for improvement (Pyster, Olwell, & et-al, System Deployment and Use, 2012)

2. System Maintenance

The important Considerations for the System Maintenance process according to the SEBoK are:

- Maximizing system availability to meet the operational requirements. This has to take into account the designed-in reliability and maintainability of the system and resources available.
- Preserving system operating potential through proper planning of system scheduled maintenance. This requires a reliability-centered maintenance strategy that incorporates preventive maintenance in order to preempt failures, thereby extending the mean time between corrective maintenance, as well as enhancing the availability of the system.
- Outsourcing non-critical maintenance activities so as to optimize scarce technical manpower resources.
- Harness IT technology for maintenance management. This involves rigorous and systematic capturing and tracking of operating and maintenance activities to facilitate analysis and planning (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

With the successful implementation of the maintenance process the results should be:

- a maintenance strategy is developed;
- maintenance constraints are provided as inputs to requirements;
- replacement system elements are made available;
- services meeting stakeholder requirements are sustained;
- the need for corrective design changes is reported; and
- failure and lifetime data is recorded (Pyster & Olwell, Product and Service Life Management, 2012).

The following actions and tasks should be implemented:

- system preparation for operations, including system performance verification before operation;
- scheduled servicing, such as daily inspection/checks, servicing, and cleaning;
- unscheduled servicing (carrying out fault detection and isolation to the faulty replaceable unit and replacement of the failed unit);

- re-configuration of the system for different roles or functions;
- scheduled servicing (higher level scheduled servicing but below depot level);
- unscheduled servicing (carrying out more complicated fault isolation to the faulty replaceable unit and replacement of the failed unit);
- minor modifications;
- minor damage repairs;
- major scheduled servicing (e.g., overhaul and corrosion treatment);
- major repairs (beyond normal removal and replacement tasks); and
- major modifications (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

Two final considerations listed by the SEBoK under the maintenance section are:

- Adequate training must be provided for the technical personnel maintaining the system. While initial training may have been provided during the transition process, additional personnel may need to be trained to cope with the increased number of systems being fielded, as well as to cater to staff turnover. It is important to define the certification standards and contract for the training materials as part of the supply agreement.
- The organization responsible for maintaining the system should have clear thresholds established to determine whether a change requested by end users, changes to correct latent defects, or changes required to fulfill the evolving mission are within the scope of a maintenance change or require a more formal project to step through the entire systems engineering life-cycle. Evaluation criteria to make such a decision could include cost, schedule, risk, or criticality characteristics (Pyster, Olwell, & et-al, System Deployment and Use, 2012).

3. System Upgrades

The SEBoK divides up this section into two areas, Service Life Extension (SLE) and Capability Updates, Upgrades and Modernization. The SEBoK defines SLE as:

> Product and service life extension involves continued use of a product and/or service beyond its original design life. Product and service life extension involves assessing the risks and the life cycle cost of continuing the use of the product or service versus the cost of a replacement system. Service life extension emphasizes reliability upgrades and component replacement or rebuilding of the system to delay the system's entry into wear-out status due to prohibitively expensive sustainment, reliability, safety, and/or performance requirements that can no longer be met. The goal is typically to return the system to as new of a condition as possible while remaining consistent with the economic constraints of the program. SLE is regarded as an environmentally friendly way to relieve rampant waste by prolonging the use-life of retiring products and preventing them from being discarded too early when they still have unused value. However, challenged by fast-changing technology and physical deterioration, a major concern in planning a product SLE is considering to what degree a product or service is fit to have its life extended. (Pyster & Olwell, Product and Service Life Management, 2012)
>
> The key factors and questions to consider for SLE are:

- Current life cycle costs of the system;
- Design life and expected remaining useful life of the system;
- Software maintenance;
- Configuration Management;
- Warranty policy;
- Availability of parts, subsystems, and manufacturing sources; and
- Availability of system documentation to support life extension (Pyster & Olwell, Product and Service Life Management, 2012)

The largest emphasis in this entire section of the SEBoK is cost, with the bottom line being if the cost of SLE is less than the cost of replacement than it is a course that should be pursued by the operating/managing agency. Some other considerations that are mentioned are the disruption of critical services, the effect on systems with-in a system (the NASA space program is the example given in the SEBoK) and safety in the case of highly dangerous systems (transportation aircraft and nuclear reactors) (Pyster & Olwell, Product and Service Life Management, 2012). One of the final warnings given is that for some systems there are regulatory requirements associated with SLE (Pyster & Olwell, Product and Service Life Management, 2012).

The Capability Updates, Upgrades and Modernization section starts out once again with a similar message to the SLE section, which is that costs needs to be one of the major deciding factors. A list of all the major considerations are:

- type of system (space, air, ground, maritime , and safety critical);
- missions and scenarios of expected operational usage;
- policy and legal requirements that are imposed by certain agencies or business markets;
- product or service life cycle costs;
- electromagnetic spectrum usage expected, including change in RF emissions;
- system Original Equipment Manufacturer (OEM) and key suppliers, and availability of parts and subsystems;
- understanding and documenting the functions, interfaces, and performance requirements, including environmental testing and validation;
- system integration challenges posed by the prevalence of system-of-systems solutions and corresponding interoperability issues between legacy, modified, and new systems; and
- the amount of regression testing to be performed on the existing software (Pyster & Olwell, Product and Service Life Management, 2012).

The Key processes and procedures that need to be considered are:

- legislative policy adherence review and certification;
- safety critical review;
- engineering change management and configuration control;
- analysis of Alternatives;
- warranty and product return process implementation; and
- availability of manufacturing and supplier sources and products (Pyster & Olwell, Product and Service Life Management, 2012).

Specifically for Product Systems SEBoK emphasizes:

- product modernization involves understanding and managing a list of product deficiencies, prioritized change requests, and customer issues associated with product usage.
- product modernization uses the Engineering Change Management principle of change control boards to review and implement product changes and improvements.
- product modernization and upgrades require the use of system documentation. A key part of the product change process is to change the supporting system documentation functions, interfaces, modes, performance requirements, and limitations.
- if system documentation is not available, Reverse Engineering is required to capture the proper "as is configuration" of the system and to gain understanding of system behavior prior to making any changes.
- during system verification and validation (after product change), it is important to perform regression testing on the portions of the system that were not modified to confirm that upgrades did not impact the existing functions and behaviors of the system. The degree and amount of regression testing depends on the type of change made to the system and whether the upgrade includes any changes to those functions or interfaces involved with system safety.
- It is important to consider changes to the system support environment Change may require modification or additions to the system test equipment and other support elements such as packaging and transportation.
- Some commercial products involve components and subsystems where modernization activities cannot be performed. An example of these types of commercial systems are consumer electronics, such as radios and computer components. The purchase price of these commercial systems is low enough that upgrades are not economical and are considered cost prohibitive (Pyster & Olwell, Product and Service Life Management, 2012).

For Service Systems the SEBoK recommends:

- Service system modernization may require regulatory changes to allow the use of new technologies and new materials. Service system modernization requires backward compatibility to previous provided service capability during the period of change.

- Service system modernization, which spans large geographical areas, requires a phased-based change and implementation strategy. Transportation systems such as highways (i.e., Interstate Highways) provide service to many different types of consumers and span such large geographical areas.
- Modernization often requires reverse engineering prior to making changes to understand how traffic monitoring devices such as metering, TV cameras, and toll tags interface with the rest of the system (Pyster & Olwell, Product and Service Life Management, 2012).

For Enterprises the SEBoK recommends:

- Enterprise system modernization must consider the location of the modification and the conditions under which the work will be performed. The largest challenge is implementing the changes while the system remains operational. In these cases, disruption of ongoing operations is a serious risk. For some systems, the transition between the old and new configuration is particularly important and must be carefully planned.
- Enterprise system modernization requires coordination of changes across international boundaries. Enterprise modifications normally occur at a lower level of the system hierarchy. Change in requirements at the system level would normally constitute a new system or a new model of a system.
- The Chapter Guidebook (2010) discusses the change to the architecture of the system. In cases where a component is added or changed, this change will constitute a change to the architecture.
- As an example, the global positioning system (GPS) is an enterprise system implemented by the US military but used by both commercial and government consumers worldwide. Modernization may involve changes to only a certain segment of the enterprise, such as the ground user segment to reduce size, weight, and power. Modernization may only occur in certain geographical areas of operation.
- The air transportation system consists of multiple countries and governing bodies dispersed over the entire world. Changes can occur locally or can require coordination and integration worldwide (Pyster & Olwell, Product and Service Life Management, 2012).

The next area of this section addresses concurrent modification management methods and suggests two different methods if this approach is to be utilized:

- The first method is called the “block” method. This means that a group of systems are being modified simultaneously and will be deployed together as a group at a specific time. This method is meant to ensure that at the end state, all the modifications have been coordinated and integrated so there are no conflicts and no non-compliance issues with the system-level requirements.
- The second method is called continuous integration and is meant to occur concurrently with the block method. Information management systems provide an example of a commercial system where multiple changes can occur concurrently. The information management system hardware and network modernization will cause the system software to undergo changes. “Software release management is used to coordinate the proper timing for the distribution of system software changes to end-users””. (Pyster & Olwell, Product and Service Life Management, 2012)

The final area of this section addresses Commercial Off the Shelf (COTS) items and the benefits and risks associated with them. The advantages are that COTS items provide increased functionality, continually shrinking size and lower typical costs than specialized products. The primary disadvantages for COTS items are obsolescence and changes to system interface. SEBoK concludes with the thought that extensive consideration needs to be given to form factor and electrical and physical interface (Pyster & Olwell, Product and Service Life Management, 2012).

4. System Disposal

According to the SEBoK, the reasons for systems disposal are that at some point a system will become uneconomical to maintain, obsolete or unrepairable (Pyster & Olwell, Product and Service Life Management, 2012). Some of the concerns for System Disposal listed by the SEBoK are:

- In addition to technological and economical factors, the system being developed must be compatible, acceptable, and ultimately address the design of a system for the environment in terms of ecological, political, and social considerations.

- In particular, the ecological considerations associated with system disposal or retirement is of prime importance. The most concerning problems of dealing with waste are identified below.
    - Air Pollution and Control
    - Water Pollution and Control
    - Noise Pollution and Control
    - Radiation
    - Solid Waste
- In the United States, the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) govern disposal and retirement of commercial systems; equivalent organizations perform this function in other countries (Pyster & Olwell, Product and Service Life Management, 2012).

The listed applications for Product Systems are:

- Product system retirement may include system disposal activities or preservation activities (e.g., mothballing) if there is a chance the system may be called upon for use at a later time. OSD AT&L provides guidance for the preservation of military systems, such as naval ships and aircraft.
- ““Systems Engineering and Analysis has several chapters that discuss the topics of design for goals such as “green engineering,” reliability, maintainability, logistics, supportability, producibility, disposability, and sustainability. Chapter 16 provides a succinct discussion of “green engineering” considerations and “ecology-based manufacturing.” Chapter 17 discusses life cycle costing and the inclusion of system disposal and retirement costs.””
- Some disposal of a system's components occurs during the system’s operational life. This happens when the components fail and are replaced. As a result, the tasks and resources needed to remove them from the system need to be planned well before the actual demand for disposal occurs. Planning must consider transportation of failed items, handling equipment, special training requirements for personnel, facilities, technical procedures, technical documentation updates, hazardous material (HAZMAT) remediation, all associated costs, and reclamation or salvage value for precious metals and recyclable components. ““Phase-out and disposal

planning addresses when disposal should take place, the economic feasibility of the disposal methods used, and what the effects on the inventory and support infrastructure, safety, environmental requirements, and impact to the environment will be."" ""Disposal is the least efficient and least desirable alternative for the processing of waste material.""

- The EPA collects information regarding the generation, management, and final disposition of hazardous wastes regulated under the Resource Conservation and Recovery Act of 1976 (RCRA).
- EPA waste management regulations are codified at 40 C.F.R. parts 239-282. Regulations regarding management of hazardous wastes begin at 40 C.F.R. part 260. Most states have enacted laws and promulgated regulations that are at least as stringent as federal regulations. Due to the extensive tracking of the life of hazardous waste, the overall process has become known as the cradle-to-grave system. Stringent bookkeeping and reporting requirements have been levied on generators, transporters, and operators of treatment, storage, and disposal facilities that handle hazardous waste.
- See the EPA website for a comprehensive list of wastes, including resource conservation, hazardous wastes, and non-hazardous wastes.
- Unfortunately, disposability has a lower priority compared to other activities associated with product development. This is due to the fact that, typically, the disposal process is viewed as an external activity to the entity that is in custody of the system at the time. Some of the reasons behind this view include:
    - There is no direct revenue associated with the disposal process and the majority of the cost associated with the disposal process is initially hidden.
    - Typically, someone outside of systems engineering performs the disposal activities, thus the "not my problem" attitude is common. For example, neither a car manufacturer nor the car's first buyer may be concerned about a car's disposal since the car will usually be sold before disposal.
- The European Union's Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) regulation requires manufacturers and importers of chemicals and products to register and disclose substances in products when specific thresholds and criteria are met (European Parliament 2007).

The European Chemicals Agency (ECHA) manages REACH processes.

- Numerous substances will be added to the list of substances already restricted under European legislation; for example, a new regulation emerged when the Restriction on Hazardous Substances (RoHS) in electrical and electronic equipment was adopted in 2003.
- Requirements for substance use and availability are changing across the globe. Identifying the use of materials in the supply chain that may face restriction is an important system life management consideration. System disposal and retirement requires upfront planning and the development of a disposal plan to manage the activities. An important consideration during system retirement is the proper planning required to update the facilities needed to support the system during retirement, as explained in the *California Department of Transportation Systems Engineering Guidebook*.
- Disposal needs to take into account environmental and personal risks associated with the decommissioning of a system and all hazardous materials need to be accounted for. The decommissioning of a nuclear power plant is a prime example of hazardous material control and exemplifies the need for properly handling and transporting residual materials resulting from the retirement of certain systems.
- The Defense Logistics Agency (DLA) is the lead military agency responsible for providing guidance for worldwide reuse, recycling, and disposal of military products. A critical responsibility of the military services and defense agencies is demilitarization prior to disposal (Pyster & Olwell, Product and Service Life Management, 2012).

The application for Service Systems are:

- An important consideration during service system retirement or disposal is the proper continuation of services for the consumers of the system. As service systems are retired, it is often integral to continue to provide the same quality and capacity of services offered by the system. As an existing service system is decommissioned, a plan should be adopted to bring new systems online that operate in parallel of the existing system so that service interruption is kept to a minimum. This parallel operation can occur over a significant period of time and needs to be carefully scheduled.

- The *Systems Engineering Guidebook for Intelligent Transportation Systems (ITS)* provides planning guidance for the retirement and replacement of large transportation systems. ““Chapter 4.7 identifies several factors which can shorten the useful life of a transportation system and lead to early retirement, such as the lack of proper documentation, the lack of effective configuration management processes, and the lack of an adequate operations and maintenance budget”” (Pyster & Olwell, Product and Service Life Management, 2012).

There is only one listed application for Enterprises and it is:

- The disposal and retirement of large enterprise service systems requires a phased approach where capital planning is implemented in stages. As is the case of service systems, an enterprise system's disposal and retirement require parallel operation of the replacement system along with the existing (older) system to prevent loss of functionality for the users of the enterprise (Pyster & Olwell, Product and Service Life Management, 2012).

The final section of this area discusses the need to recycle systems and the importance of that recycling not having an adverse effect on the environment. It also discusses the emerging area of “green engineering” and how important that concept and methodology is for the future of the environment and the planet (Pyster & Olwell, Product and Service Life Management, 2012). This concept is certainly becoming more important since the planet has limited resources and it is good practice to try and re-use materials whenever possible. This concludes the in-service portions of the SEBoK.

5. Unique Features

In addition to being the most comprehensive and lengthy of the industry standards that have been examined for this thesis the SEBoK also has a unique attribute and that is the revision plan. The editors of the SEBoK envision a constant revision an update process, with new versions coming out approximately every six months (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012). The method of revision involves accepting omissions, mistakes and suggested changes or updates from readers and users of the document (Pyster, Olwell, & et-al, System Engineering Body of

Knowledge, V 0.75, 2012). This constant revisions process should help to ensure the that the SEBoK captures to the most relevant information and techniques related to SE that are being used in academic and practical environments. The only major drawback that seems to be the potential for the editors to be overwhelmed by large numbers of submissions which can add to the length of time in-between updates.

6. Summary

The SEBoK has good coverage of Operations, Maintenance, Service Life Extension, Upgrades and Disposal processes. The only missing item from the SEBoK is an emphasis on the need for data gathering during the Maintenance period. The SEBoK is not the “best” at each section but the overall content is better written and taken as a whole presents a better product that the ISO 15288 and INCOSE SE Handbook for in-service engineering items. The SEBoK still only provides a list of what needs to be done for in-service systems engineering, it does not say how to do something and that is what will be required by the NSEG.

IV. STANDARD COMPARISON

A. NSEG VS. INDUSTRY STANDARDS

1. Introduction

As was stated in the previous chapter the NSEG does not have sections or information on in-service engineering. Because of this fact, all of the comparisons will be performed between the industry standards. From these comparisons, conclusions will be drawn about the importance of such sections and which standard is the best model for future revisions to the NSEG.

Table 2 summarizes the findings from the four documents by listing the most important aspects of each of the in-service sections and noting how they address the material. If there is no discussion than "None" appears in the column, some coverage than "Partial Cover" appears in the column and finally if the subject is properly addressed "Cover" will appear in the column. Some of the factors leading into the coverage labels are word count, diagrams and specific points made.

	NSEG	ISO 15288	INCOSE	SEBoK
Operations				
Standards	None	None	Cover	Cover
Data Gathering	None	None	Partial Cover	Cover
Training	None	Cover	Partial Cover	Cover
Customer Support	None	Partial Cover	Partial Cover	Cover
Maintenance				
Standards	None	None	Cover	Cover
Data Gathering	None	Cover	Cover	None
Training	None	Partial Cover	Partial Cover	Cover
Service Life Extension				
Cost	None	None	None	Cover
Obsolecence	None	None	None	Cover
Disposal				
Standards	None	None	Partial Cover	Cover
Data Gathering	None	Cover	Cover	Cover
Enviromental Concerns	None	Partial Cover	Cover	Cover

Table 2. Comparison Standards Summary

Containing large amounts of content is not always an indicator of “good” coverage but it can give an indicator of importance placed on a subject. Table 3 is a compilation of the number of words each standard has concerning a particular subject area. While length is not a substitute for content it is usually a good indicator something that the author/editor felt was important and thus added an appropriate level of content.

	NSEG	ISO 15288	INCOSE	SEBoK
Operations	0	669	647	1199
Maintenance	0	590	628	746
Service Life Extension	0	0	0	3538
Disposal	0	652	845	1525
Total In-Service SE	0	1911	2120	7008

Table 3. Word Count for Standards

2. Operations Summaries

The ISO 15288 breaks the Operations down into three basic sections: Purpose, Outcomes and Activities and tasks. The Purpose is the definition of the “Operations Process,” the Outcomes are what you get as the result of a “successful implementation” of the process, and the Activities and tasks are what need to be done to achieve those outcomes. There are four desired outcomes and five activities and tasks that are listed and the activities and tasks each have one to three subtasks listed. This section contains some detail but is less than two pages for the entire amount of material for Operations (Roedler & Jones, 2008).

The INCOSE Handbook contains five sections: Purpose, Description, Inputs, Outputs and Process Activities. The Purpose is almost word for word the same as the Purpose in the ISO 15288. The Description explains exactly what the Operations process is and includes a useful diagram that summarizes all other sections of the Operations process (Figure 1 in Chapter III). The Inputs section describes all of the inputs, enablers and controls that feed into the Process Activities. The Outputs section describes all of the expected outcomes of the Operations Process and finally the Process Activities describe all of the activities that get you to the Outputs with the aid of the Inputs, Enablers and Tasks. The final portion of the sections gives “common approaches and tips” and the entire section is three and a half pages long (Haskins, 2011).

The SEBoK begins similarly to the INCOSE SE Handbook in that it begins with the definition of Operations from the ISO 15288 but it also utilizes the descriptions from the INCOSE SE Handbook in their “description” section. This first section also foreshadows the use of Service Life Extension (SLEP) and system Disposal as parts of the System Engineers job. This is one of three major sections, the other two being Process Approaches and Practical Considerations. The Process Approaches lists important data for Systems Engineers to gather and applicable tools and methods for the Operations Process and is intensive on data and explanation. The Practical Considerations section has a brief description and then lists the Outputs and Process Activities for the Operations Process. This section is a little over two and a half pages long (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012).

3. Maintenance Summaries

The ISO 15288 breaks the Maintenance Section into three sections: Purpose, Outcomes and Activities and Tasks. The Purpose is the definition of the “Maintenance Process,” the Outcomes are what you get as the result of a “successful implementation” of the process and the Activities and tasks are what needs to be done to achieve those outcomes. There are six desired outcomes and two sections of activities and tasks that are listed. The activities and tasks are broken down into Plan Maintenance and Perform Maintenance sections and each section has multiple subsections. This is sections contains some detail but is less than two pages for the entire amount of material for Maintenance (Roedler & Jones, 2008).

The INCOSE Handbook contains five sections: Purpose, Description, Inputs, Outputs and Process Activities. The Purpose is almost word for word the same as the Purpose in the ISO 15288. The Description explains exactly what the Maintenance process is and includes a useful diagram that summarizes all other sections of the Maintenance process (Figure 2 in Chapter III). The Inputs section describes all of the inputs, enablers and controls that feed into the Process Activities. The Outputs section describes all of the expected outcomes of the Operations Process and finally the Process Activities describe all of the activities that get you to the Outputs with the aid of the Inputs, Enablers and Tasks. The final portion of the sections gives “common approaches and tips” and the entire section is three and a half pages long (Haskins, 2011).

The SEBoK System Maintenance section also begins with the definition from the ISO 15288 and then moves into the main considerations that need to be kept in mind during the process. The SEBoK then moves into its Process Approaches and Practical Considerations. The Process Approaches section covers the desired Outcomes, the Activities and Tasks and the Methods and Tools for the Maintenance Section. The Practical Considerations is rather limited and discusses changes in scope on Maintenance and how they should be handled. This entire section is less than two pages long (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012).

4. Service Life Extension Summaries

The ISO 15288 and INCOSE SE Handbook do not discuss system lifecycle extension and/or system upgrades.

The SEBoK breaks extension and upgrades into two different sections. The SLE section begins with a description of key factors to consider and then defines those factors in the context of SLE. The next sections are how these particular key topics apply to Product Systems, Service Systems and Enterprises. Finally, the Practical Applications section ends with what is usually the limiting factor for SLE and that is the costs. This section is five pages long and contains extensive detail and reference material (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012).

The Capabilities Update, Upgrades, Modernization (CUUM) section begins with the definitions of what each of those items is, and what the possible reasons are for pursuing them. The next section discusses Key Factors and Key Processes and Procedures to consider. The next sections are how these particular key topics apply to Product Systems, Service Systems and Enterprises. The SEBoK then gives a “V” model example of how this can be represented and then discusses Practical Considerations. The ending Practical Consideration is a discussion on Commercial off the Shelf (COTS) items and the benefits and dangers associated with them. This section is five pages long and contains extensive detain and reference material (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012).

5. Disposal Summaries

The ISO 15288 breaks the Disposal Section into three sections: Purpose, Outcomes and Activities and Tasks. The Purpose is the definition of the “Disposal Process”, the Outcomes are what you get as the result of a “successful implementation” of the process and the Activities and tasks are what needs to be done to achieve those outcomes. There are five desired outcomes and three sections of activities and tasks that are listed. The activities and tasks are broken down into Plan Disposal, Perform Disposal and Finalize the Disposal sections and each section has multiple subsections. This is sections contains some detail but is less than two pages for the entire amount of material for Maintenance (Roedler & Jones, 2008).

The INCOSE Handbook contains five sections: Purpose, Description, Inputs, Outputs and Process Activities. The Purpose is almost word for word the same as the Purpose in the ISO 15288. The Description explains exactly what the Disposal process is and includes a useful diagram that summarizes all other sections of the Disposal process (Figure 3 in Chapter III). The Inputs section describes all of the inputs, enablers and controls that feed into the Process Activities. The Outputs section describes all of the expected outcomes of the

Operations Process and finally the Process Activities describe all of the activities that get you to the Outputs with the aid of the Inputs, Enablers and Tasks. The final portion of the sections gives “common approaches and tips” and the entire section is three and a half pages long (Haskins, 2011).

The SEBoK begins with the definition of System Disposal and with an emphasis on all of the environmental concerns that need to be addressed when the system is being designed. It utilizes the definition from the INCOSE SE Handbook and cites EPA and OSHA requirements for US products. The next three sections discuss applicability to Product Systems, Service Systems and Enterprises and further report various environmental and regulatory agencies for various countries and continents. The ending Practical Considerations section discusses the importance of “green engineering” and the long-term effects for the environment (Pyster, Olwell, & et-al, System Engineering Body of Knowledge, V 0.75, 2012).

B. INCOSE SE HANDBOOK VS ISO 15288

1. Operations

The INCOSE manual begins each of its sections with the definition of the particular area from the ISO 15288 so it would be safe to call it the parent manual. The reason given for revising some of the earlier versions to the INCOSE SE Handbook are to write an “Updated version based on ISO/IEC 15288:2008; resubmitted to ISO/IEC for consideration as an ISO/IEC Technical Report” (Haskins, 2011). This commonality is maintained throughout the standards with the biggest difference being the level of detail placed into the INCOSE manual.

The INCOSE manual has a similar number of Outcomes/Outputs to the ISO 15288 with the big difference being the amount of detail added to the INCOSE manual. The System Description only appears in the INCOSE manual and only the INCOSE manual has diagrams. The INCOSE manual places a high importance on standards, rules and regulations that need to be implemented.

Both manuals emphasize the importance of training and the creation of feedback loops for correcting procedures as more time is spent operating the system. Both manuals also point out the importance of supporting the customer for the creation of trust and because it aids in fixing issues that arise if all parties are working well together. Both manuals seem to do an adequate job for the Operations Processes.

2. Maintenance

The INCOSE SE Handbook has a similar number of Outcomes/Outputs to the ISO 15288, with the big difference being the amount of detail added to the INCOSE manual. The System Description only appears in the INCOSE manual and only the INCOSE manual has diagrams. The items that are readily noticeable as missing from the ISO 15288 are from the Controls section of the INCOSE manual and those include Applicable Laws and Regulations, Industry Standards and Project Directives and Standards. Both manuals emphasize the importance of maintaining records for historical and correction purposes, and both manuals emphasize the importance of proper tools, training and personnel to properly perform the Maintenance. Both manuals seem to do an adequate job for the Maintenance section.

3. System Life Extension

Neither the ISO 15288 nor the INCOSE SE Handbook discusses the areas of Service Life Extension or System Upgrades.

4. Disposal

The INCOSE SE Handbook and ISO 15288 have a similar focus for disposal in the emphasis on disposing to protect the environment. The INCOSE manual has a similar number of Outcomes/Outputs to the ISO 15288 with the major difference being the amount of detail added to the INCOSE manual. The System Description only appears in the INCOSE manual and only the INCOSE manual has diagrams. The items that are readily noticeable as missing from the

ISO 15288 are from the Controls section of the INCOSE manual and those include Applicable Laws and Regulations, Industry Standards and Project Directives and Standards. The INCOSE manual places a heavy emphasis on environmental and green disposal while the ISO 15288 just glances over that aspect. Both manuals emphasis the importance of having a defined disposal plan early on in the engineering process and both emphasis the importance of keeping good historical records on the process so that lessons can be learned and it can be proven that disposals were done properly. Both manuals successfully describe the Disposal process but the INCOSE manual would have to be defined as "better" because of the current importance for environmental and recycling concerns.

C. ISO 15288 VS SEBOK

1. Operations

The SEBoK begins with a data analysis section that is not present in the ISO 15288. Both references emphasize the importance of training but the SEBoK goes into greater depth and detail on specifically what needs to be done at each step to make training effective and to ensure that proper tools and support are available for the operators. Both manuals discuss feedback loops and the importance of supporting the customer and both manuals have similar Outputs/Outcomes and activities which create them. Overall, it would seem that a combination of elements from both of these manuals would be needed to create a functional Operations section.

2. Maintenance

The first readily noticeable omission from the SEBoK that is written into the ISO 15288 is the importance of maintaining a history all maintenance issues, problems and corrective actions for revisions and similar projects in the future. The SEBoK contains a list of important considerations that are not listed in the ISO 15288 and these considerations place great importance on the maintaining of maintenance schedules in order to allow the product to complete its

Operations (which it cannot do if it is down for repairs, either scheduled or unscheduled). Both manuals emphasize the importance of proper training, tools and support for maintenance personnel to perform their jobs. Both manuals also emphasize the importance of having consistent maintenance procedures and timetables for repair so that products are fixed the same way each time. Both manuals perform an adequate job of pointing out the importance of Maintenance operations but a combination of both manuals would probably give the best solution because of the glaring omissions.

3. System Life Extension

There is no need for comparison since the ISO 15288 does not address SLE.

4. Disposal

The SEBoK has a similar focus to the ISO 15288 in the emphasis on the importance of properly disposing of the system to minimize the effects on the environment. The ISO 15288 uses general terms and ideas while the SEBoK is significantly more detailed especially in the case of different types of pollution and environmental concerns and agencies that affect disposal processes. The ISO 15288 also does not specifically address green engineering or break the processes down by category. The ISO 15288 does emphasize the importance of maintaining a concise set of records and history of what was done for both a learning point and to satisfy all legal considerations. The SEBoK emphasizes not only the environmentally safe disposal of products but also discusses the importance of recycling whatever can be used again. The SEBoK is once again much more detailed than the ISO 15288 on the topic of Disposal and would seem to offer the best solutions for inclusion in a manual.

D INCOSE SE HANDBOOK VS. SEBOK

1. Operations

The *SEBoK* and the *INCOSE SE Handbook* both recommend data gathering but the *SEBoK* has a more extensive and informative section on what to gather and why it is necessary to have. Both manuals also discuss training but the *SEBoK* has a more thorough section on this and greatly emphasizes the importance of proper training and the various areas that should be emphasized to ensure the appropriate training level is reached. The INCOSE manual does emphasize regulations, standards and laws more than the *SEBoK* does, and also places a greater emphasis on the customer/manufacturer feedback loop. Overall, it seems that combining these two manuals will get you a “best solution” for Operations.

2. Maintenance

The SEBoK begins with some important considerations that are not covered by the INCOSE SE Handbook but the INCOSE manual once again emphasizes documents, laws and regulations that are not found in the SEBoK. Both manuals emphasize the importance of having the proper tools and training for maintenance personnel, and the important of maintaining records to help facilitate improvement on those processes. Both manuals also emphasize the importance of scheduling, downtime and the importance of proper support. Aside from a few minor differences both of these manuals do a good job of covering the Maintenance processes.

3. System Life Extension

There is no need to discuss SLE in that the INCOSE SE Handbook does not have a section on it.

4. Disposal

Both the SEBoK and INCOSE SE Handbook place heavy emphasis on environmental protection and “green” disposal of items, and they both thoroughly discuss the regulations, laws and applicable agencies that affect disposal. The SEBoK does a better job of actually pointing out which agencies are directly responsible but both lead you in the proper direction. Both instructions point out the importance of System Disposal being part of the initial design construction and not something that is an “afterthought” once the system is getting towards the end of its life and needs to be disposed of. The INCOSE manual even states that this process will need to be updated as changes are made to the system and to laws/regulations that might affect it. Overall, both of these manuals do an excellent job of explaining the Disposal process.

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V. CONCLUSIONS & RECOMMENDATIONS

A. INTRODUCTION

1. Introduction

Based on the inclusion of in-service engineering aspects in the ISO 15288, INCOSE SE Handbook and SEBoK, it is safe to conclude that these aspects are important parts of Systems Engineering that should be included in future revisions of the NSEG. The in-service engineering areas that were discussed in this thesis cover a significant amount of time of a systems life and need to be covered by future revisions of the NSEG. It is important to note that all three of the SE references that were reviewed for this thesis only point out what needs to be done at certain points of the process. Details on how to conduct in-service systems engineering in a Navy context would still need to be developed in the NSEG.

B. RECOMMENDATIONS FOR IMPROVEMENT TO NSEG

1. In-Service Engineering

In-service Engineering is an important aspect of SE and the four areas discussed here should be included in future revisions to the NSEG. An Aircraft Carrier might take 20 years to design and build, and then sail for 50+ years on the open seas (Federation of American Scientists, 2011). There will be a large number of changes over the course of the ship's lifetime and using SE principles to govern those changes will make them more effective and efficient in the end. By not having a common Navy standard, projects will be at the mercy of Industry standards that while acceptable for the most part are also very different on some aspects. These differences can be very great for similar products made by different companies utilizing different standards. The following sections provide recommendations for each area of in-service engineering for future revisions to the NSEG.

2. Operations

None of the three industry standards discussed in this paper completely satisfied the Operations Process. There were “good” and “bad” elements for each item, and taking that into account the recommended pieces for the NSEG would be:

- Adopt an overall Model similar to the INCOSE one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- The five elements from this diagram and program would be populated from all three manuals.
- Adopt the Data Gathering Suggestions from SEBoK, to provide the necessary data for studying various operations and functions so that improvements can be made for future iterations.
- Adopt the emphasis on Customer Support and Feedback from ISO, as having good communication is vital to maintaining a healthy relationship between all involved parties.

3. Maintenance

There were many useful attributes described in each of the standards that would be useful to Naval Systems Engineers in a revision to the NSEG. The following suggestions are combinations of ideas taken from all three of the standards:

- Adopt an overall Model similar to the INCOSE one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- The five elements from this diagram and program would be populated from all three manuals.
- Adopt the emphasis on historical records from the ISO 15288 and INCOSE Handbook, as maintaining diligent records will aid in making changes and updates to maintenance procedures, tools and personnel qualifications.
- Adopt the emphasis on training that is included in all three manuals.
- Adopt the emphasis on consistency to establish a pattern for various Maintenance activities, this will allow new methods and

Operational changes to be made if necessary (i.e., more downtime than originally planned or retraining of Operational techniques because they are putting undue wear and tear on certain components).

4. Service Life Extension

The SEBoK is the only one of the three standards that addresses Service Life Extension and Capabilities Update, Upgrades and Modernizations so the recommendations will be drawn primarily from there with some formatting ideas taken from the INCOSE SE Handbook. This area should be broken down into two sections, first SLE:

- Adopt an overall Model similar to the INCOSE one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- Adopt an emphasis on cost, as in order to extend a system it must be more cost effective than a replacement product in both the short and long term while performing maintenance.
- Adopt an emphasis on obsolescence, to keep the spare parts, tools and qualified personnel on hand to keep the products running.

Capabilities Update, Upgrades and Modernizations:

- Adopt an overall Model similar to the INCOSE one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- Adopt an emphasis on cost, as in order to modernize or upgrade a system it must be more cost effective than a replacement product for the system would be, both short term and long term.
- Adopt an emphasis on obsolescence. Are the spare parts, tools and qualified personnel on hand to keep the products running? If not then upgrades or modernizations may be required to keep the system running and/or in production.

5. Disposal

System Disposal seemed to gain the most interest from the standards because of the importance and ramifications that come from this portion of the lifecycle. There were good elements from all three standards and the following sections of suggestions are a combination of those desirable elements:

- Adopt an overall Model similar to the INCOSE one, with Inputs, Enablers and Controls feeding into Activities that give us Outputs. The diagram format that they use is informative from a summary purpose and should be included as well.
- The five elements from this diagram and program would be populated from all three manuals.
- Adopt the emphasis on environmental concerns for disposal and recycling that are present in all three manuals.
- Adopt an emphasis on record keeping to preserve data for historical reference and as proof that products were properly disposed of IAW all applicable laws, standards and regulations.
- Adopt an emphasis on making Disposal plans part of the process from the very beginning, and plan that they will be modified to address changes in the product itself and changing laws and regulations that govern it over the course of its lifetime.

C. RECOMMENDATIONS FOR FURTHER STUDY

1. Other Areas of the NSEG

This thesis only focused on the in-service aspects of SE. There are many other attributes in the system lifecycle that need to be examined and studied to ensure that the NSEG is not missing any other relevant data, methods or tools in its processes. This would involve a similar methodology to what was employed in this thesis: first examine the NSEG to see what it has about a particular area of interest and then examine industry standards (either the ones used here or the ones discussed in the next section, ideally all) to see how they match up. This would be an involved and lengthy process due to the many areas that need to be covered and might in fact take several revisions to complete.

2. Other Standards

The ISO 15288, INCOSE SE Handbook and SEBoK were the three standards that this study was limited to, due to time and resource constraints. There are other standards for SE that might contain other data or ideas that would be useful to Naval SE. Some of the other well recognized and utilized standards include the NASA/SP-2007-6105 (systems engineering handbook) (NASA Chief Engineer, 2007), the MITRE SE Handbook (MITRE Corporation, 2012) and the ECSS E-10 (European Space Agency) (ECSS Secretariat, 1996). These standards all give similar information to the standards discussed in this thesis, but have different ideas approaches based on their contexts that could aid in development of a new version of the NSEG.

In addition to reviewing standards, it would be good to have staffs working on this project that are well versed in several prominent systems engineering textbooks. These textbooks often give examples, models and techniques to follow in addition to presenting the general information that is found in standards. Some of the more widely used SE textbooks are "Systems Engineering and Analysis" (Blanchard & Fabrycky, 2010), "Control Systems Engineering" (Nise, 2010), "Systems Engineering Principles and Practice" (Kossiakoff, Sweet, Seymour, & Biemer, 2011), "System Analysis, Design, and Development: Concepts, Principles, and Practices" (Wasson, 2005) and "Introduction to Systems Engineering" (Sage & Armstrong Jr., 2000)". By combining these books and with the aforementioned standards there would be a more complete coverage of all areas of concern related to SE topics.

3. Continual Revisions

Another important point to make is that this NSEG update cannot be a onetime occurrence. There are new systems engineering tools and methods being developed all the time and only be performing periodic market surveys can these items be captured. The initial rework of the NSEG will be a time consuming and expensive process because of the long time since it was originally written, but subsequent revisions should be easier to accomplish as long as the periodicity is kept down.

To promote this positive revision there should be a market survey performed every 3-4 years, that examines current revisions to industry SE standards and determines if there are significant enough changes to warrant an update to the NSEG or certain sections of it. There needs to be an assigned Program Manger to this process to ensure that the surveys are done both timely and effectively. From these surveys the Program Office will need to determine whether or not a revision is warranted for the NSEG.

D. CONCLUSIONS

The NSEG is deficient in its discussion of the in-service areas of study including Operations, Maintenance, Service Life Extension, Capability Upgrades and Disposal. There is extensive information in the three industry standards that were examined for this thesis (ISO 15288, INCOSE SE Handbook and the SEBoK) and in several other standards that were mentioned in the recommended further research section of this chapter. Because these sections were not only included in these standards but also given significant coverage it is safe to assume that they are important to a successful system and should be included in future revisions to the NSEG. The industry standards for the most part contain the “what” of should be done so once the Navy decides which models it prefers they will have to fill in the “how” portions of the process.

There will be a continually evolving threat to the United States and its allies and there will be both old weapons that are adapted to meet this threat and new ones that need to be created to respond to these threats (Greenert, 2012). By including in-service engineering in the NSEG and by continually updating its processes and procedures every few years the Navy can ensure that the NSEG is giving its work force the best tools from a systems engineering perspective to meet these new threats. This does not guarantee that the best services or systems will make it into the hands of war fighters but it will help to ensure that the best techniques are being used. These techniques will increase the likelihood that the Navy is getting the proper “bang for its buck” and that systems operate more smoothly and efficiently than those that do not utilize proper techniques.

APPENDIX

SUGGESTED TABLE OF CONTENTS FOR NSEG REVISION:

- System Operations
  - System Diagram with Enablers, Controls, Inputs, Activities and Outputs
  - System Operating requirements and parameters
  - Operator requirements and training
  - Operations data gathering requirements
  - Customer support/feedback requirements
  - Mission examination for equipment suitability, including submissions especially for larger platforms such as ships and submarines
  - Operations Execution
  - Differences between systems commands
- System Maintenance
  - System Diagram with Enablers, Controls, Inputs, Activities and Outputs
  - System Maintenance requirements and parameters
  - Maintenance worker requirements and training
  - Maintenance data gathering requirements
  - Maintenance feedback requirements
  - Division of maintenance between ships force and shipyard level work (intermediate, long term, etc.)
  - Maintenance Execution
  - Mining maintenance data
- System Service Life Extension
  - System Diagram with Enablers, Controls, Inputs, Activities and Outputs
  - Obsolescence issues including personnel, parts and tools
  - Cost analysis
  - Reliability analysis

    - Mission analysis to include capabilities to address current and near future perceived threats
    - SLE Execution
- System Capabilities Upgrade
    - System Diagram with Enablers, Controls, Inputs, Activities and Outputs
    - Obsolescence issues including personnel, parts and tools
    - Cost analysis
    - Resolving Integration Issues
    - Mission analysis to include “needs vs. wants” for current threats or perceived lifetime threats
    - Planned upgrades for “blocks” of ship or sub construction
    - Capability upgrade execution
- System Disposal
    - System Diagram with Enablers, Controls, Inputs, Activities and Outputs
    - Environmental Concerns for System
    - Cost and Economic Analysis
    - Legal Concerns for System
    - Required Records
    - Recycling Requirements
    - Nuclear disposal requirements (if necessary)
    - Artificial reefing and or weapons target/demonstration (if appropriate), including proper environmental and cleaning requirements
    - Mothballing requirements (if necessary)
    - Formation of the Disposal plan
    - Modifications to the Disposal plan
    - Executing Disposal plan

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